For Review Purposes Only

THE ENVIRONMENT OF THE UNITED STATES
LIVING MARINE RESOURCES
1974

MARMAP

Contribution No. 104

(Marine Resources Monitoring, Assessment, and Prediction Program)

Compiled by Julien R. Goulet, Jr.

January 1976

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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INTRODUCTION

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program is an NMFS national program providing information needed for management and allocation of the Nation's marine fishery resources. The program encompasses the collection and analysis of data to provide basic information on the abundance, composition, location, and condition of the commercial and recreational marine fishery resources of the United States.

Changes in physical and chemical properties of the ocean (currents, temperature, nutrients, etc.) directly or indirectly affect not only long-term yields and annual abundances of fish stocks, but also their distribution. MARMAP oceanography activities include the analyses of physical, chemical, and biological oceanographic data collected during MARMAP surveys and from oceanographic and meteorological operational and research activities of other agencies.

The MARMAP program places emphasis on providing information in a usable manner. Part of this approach involves the preparation of annual summary reports on the status of the United States marine fisheries resource (Status of Stocks - SOS) and on the status of the environment influencing those resources (Status of Environment - SOE).

This report, the Environment of the United States Living Marine Resources - 1974, is the first SOE. It presents an overview of the environment of the living marine resources of the United States. This overview contributes to the understanding necessary for optimal development, allocation, management, and control of our living marine resources.

The report includes contributions from oceanographers and meteorologists both inside and outside of the NMFS. The emphasis of these contributions is toward an understanding of the oceans as a dynamic system rather than a static one, and toward an understanding of causal relations between the environment and the resource rather than simple correlations.

Attempts have been made in the past to develop correlations between fish catch and properties traditional available to marine biologists such as temperature, salinity, oxygen concentration, and nutrient concentration. In some cases significant correlations have been found but more often correlations have held for a while and then have broken down. The fact is that the simplistic approach to the fishery-environment problem has only limited value, but is frequently a necessary first step. Knowledge of the dynamics of the relation of fish populations to their environment is vital. Indices of environmental processes of significance to life in the sea, such as upwelling, can now be made available in addition to the properties that have traditionally been available. Such indices can be derived from oceanographic and meteorological observations and are usually time dependent. Measures of the seasonal and interyear changes of time-dependent parameters that are known to affect the survival of early life stages and recruitment of fishes as well as the distribution and concentration of fishes at all stages of development are now becoming state of the art. Their analysis and interpretation is a goal of the SOE and may go a long way towards improving a number of population dynamics models.

ATLANTIC

by

Merton C. Ingham and Julien R. Goulet, Jr.

The oceanographic area of the Atlantic Ocean of principal concern to NMFS scientists includes the waters over the U.S. continental shelf and adjacent slope seaward to the Gulf Stream and the waters of the northern Gulf of Mexico. These waters are subject to considerable periodic and aperiodic variation in wind stress, precipitation and run-off, temperature and water mass properties. In this changing environment reside demersal and pelagic organisms with variable biological cycles and vital requirements. Any attempt to understand bio-environmental relationships in this area will begin with the understanding of interactions between specific physical processes or cycles and a single species or group of species with similar requirements. Understanding of ecosystems will eventually be built in this fashion, as a complex of these species-environment interactions. One of the roles of the SOE report is to portray the variation of environmental processes which have recognized or suspected significance to resource species and to describe the interactions between organisms and their environment whenever they are known.

Namias and Dickson's paper (section 3) serves as a starting point for an overview of both the Atlantic and Pacific Oceans. As a whole, 1974 was characterized by extreme strength of the mid-latitude westerlies from the western Pacific to the eastern Atlantic. The sub-polar lows and the subtropical highs were equally intense. These conditions were associated with abnormally warm sea surface temperatures in the western North Atlantic. The mean winter sea surface temperatures along the Atlantic coast were 2°F. warmer than normal and reached 5°F. warmer in the Mid-Atlantic Bight. The strength of the Bermuda High in the winter months (January-March) of 1974, which blocked the invasion of the Atlantic coastal area by polar continental air masses, also provided generally southerly and westerly winds off the Carolinas, resulting in little or no onshore transport in the ocean's upper layer. During this time period, onshore transport produced by northerly winds is critical for the success of spawning of Atlantic Menhaden south of Cape Hatteras.

Sea surface temperatures, examined by Chamberlin and Kosmark (section 16) were warmer than the long term average by more than 3°C. in Feb.-Mar. and Oct.-Dec. in the Gulf of Maine and in Jan.-Mar. over Georges Bank. Ingham (section 17) found that shoreward excursions of the shelf water front brought the front 100 kilometers more shoreward than normal over southern Georges Bank in August, covering about 14% of Georges Bank with slope water. In early September this expanded to about 18% coverage, but decreased to only 4% coverage by the end of the month, near the average for the year.

Bottom temperatures on the continental shelf and upper continental slope south of New England, as reported by Chamberlin (section 18) generally ranged from 2° to 3°C. higher throughout 1974 than the monthly mean values for 1940-66. In the warm band on the outer continental shelf, where the slope water contacts the bottom, the maximum temperatures did not fall below 12°C. during 1974, whereas the highest monthly mean values in this band fall below 10°C. from mid-February through April and below 9°C. in March. The cold core at mid-depth of the continental shelf was about 2°C warmer than the average from its formation in May to its dissipation in the autumn as a result of vertical mixing of the water column. In March, 1974, a warm core Gulf Stream eddy, which progressed generally southwestward along the edge of the continental shelf during the winter and spring, raised the bottom temperatures on the outer continental shelf and upper continental slope by as much as 4°C. Because of the unusual behavior of this eddy, its effect on shelf and slope temperatures may have been longer than is fully revealed by the available data. From early March until mid-May it resided in the waters south of New England, moving about irregularly and apparently making repetitive contacts with the bottom. It is possible that the early warming of bottom temperatures south of New England may have advanced the times of inshore spring migrations of hakes and other groundfish that winter on the outer continental shelf and upper slope. Another possibility is that in the fall the generally high bottom temperatures on the shelf may also have delayed the seasonal offshore migration of these species.

The autumn spawning of herring on Georges Bank, as reported by Bumpus (section 13) was late in 1974, beginning only in late September-early October. In mid-October there was a westward advection from the spawning area over eastern Georges Bank at a speed of 3 to 8 miles per day. There was a general dispersion from the spawning area in early November, and in late November there was a slight westward drift of 1 to 2 miles per day while the north-south extent of the area occupied by larval herring contracted slightly.

Goulet (section 19) reports water temperatures recorded at tidal stations to have been 5°F. warmer in Jan.-Feb. in 1974 than in 1973 at locations just north of Cape Hatteras in the Mid-Atlantic Bight. McLain's data (section 20) showed offshore water temperatures in the Mid-Atlantic Bight were up to 4°F. warmer in Jan.-Feb. 1974 than the long term mean. Temperature stations along the southeast U.S. coast show that 1974 was slightly warmer than 1973. Cooling in October-December was more intense in 1974 than in 1973, apparently associated with the northeasterly winds that increased shoreward transport in October.

Wind-driven transport off the southeast U.S. coast presented by Ingham (section 14) had a weak eastward component in January and a weak westward component in February 1974. The 10-year mean shows a moderate westward transport during these months. The east-west component of wind-driven transport in this season is important for the shoreward transport of larval menhaden and it is expected that larval survival in 1974 will be poorer than average. During October 1974 an unusually strong transport to the NNW occurred. This condition should have led to the close approach of oceanic waters to the coast and a strong alongshore northward current along the southeast U.S. coast.

In the Gulf of Mexico in January 1974, coastal waters just west of the Mississippi Delta were set eastward, by wind-driven transport, instead of westward as shown in the 10-year average. There was stronger than average wind-driven transport to the NNW in the central and eastern Gulf in October 1974. There was also a deeper than average penetration of the loop current (Cook and Hausknecht, section 21) in the eastern Gulf during October.

OVERVIEW OF THE PACIFIC OCEAN, 1974

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June 2-4, 1958 a group of scientists met at Rancho Santa Fe, California in an attempt to explain an extraordinary climatic change in the eastern Pacific Ocean. The unusual warming that occurred in 1957 and 1958, and events associated with it, are described in papers in proceedings of this symposium "The Changing Pacific Ocean in 1957 and 1958" edited by John Isaacs of Scripps Institution of Oceanography and the late Elton Sette of the Bureau of Commercial Fisheries. The papers presented at this meeting indicated clearly that no longer could the Pacific Ocean be thought of as invarient insofar as the environment of fishery resources were concerned; nor no longer could the atmospheric scientists ignore the varying nature of the ocean in both weather prediction and climatic change.

The following papers concerning the Pacific Ocean deal to a large extent with large scale processes. This is in keeping with comments of Isaacs and Sette in the proceedings of the symposium as follows: "It appears to the Editors that one of the most valuable results of the Symposium is to have pointed out clearly and unequivocally, and from a wide range of evidence, that locally observed changes in ocean conditions, marine fauna, fisheries success, weather, etc., are often the demonstrable result of processes acting over vast areas. In the case of local Pacific conditions, the changes obviously often are only a part of changes involving the entire North Pacific if not the entire Pacific or the entire planet.

"It appears that this realization should emancipate many provincial marine investigations and stimulate much thought and inquiry into these vast and critical events that so profoundly influence the local areas of the Pacific.

"This is to say, for example, that a basic understanding and subsequent basic forecasting of the fluctuations of a coastal fishery, probably can be best achieved by a thoughtfully limited study of the entire ocean, in addition to concentrated concern with the immediate area of the fishery."

At about this same time, Jim McGary of the Bureau of Commercial Fisheries began publishing sea surface temperature charts of the Pacific Ocean derived from merchant and naval vessel weather reports; in fact, these charts were used at the Symposium to show the degree to which warming had occurred. Publication of these charts was assumed by the Tuna Resources Laboratory, San Diego in 1960 and has since remained in that laboratory and its subsequent organization, the Southwest Fisheries Center. The charts are now published in the monthly publication, Fishing Information, as well as charts showing the subsurface temperature structure across the California Current in a program supported by the National Marine Fisheries Service, International Decade of Ocean Exploration Program of the National Science Foundation, the Navy's Fleet Numerical Weather Central and the Office of Naval Research. Over the years these charts have provided "A Status of the Environment" for the Pacific Ocean, as far as sea temperatures are concerned.

It is now time to advance this stage of reporting of the Pacific Ocean environment to another level. This first annual issue of The Environment of the United States Marine Fisheries Resource, 1974 not only will contain information on sea temperatures but also various analyses of environmental processes in 1974, i.e., air-sea interaction, upwelling, and how the changing environment affected fisheries. By the very nature of the interaction of the atmosphere, ocean and living resources therein, over-lapping of information in papers in this report occurs.

A natural starting point in describing the state of the Pacific Ocean in 1974 is to look at the large scale air-sea interactions that took place. Namias and Dickson's paper clearly describe the interaction of ocean and atmosphere over the Pacific. The year was characterized by extreme strength of the mid-latitude westerlies, especially in winter and spring. A reflection of the high index circulation over the Pacific was the large pool of cold sea surface temperature that dominated the area generally to the north of 30°N latitude. This may have been a result of open ocean-upwelling. Generally to the south of 30°N latitude and to the east of Hawaii a warmer pool of water prevailed. These conditions over the Pacific Ocean were associated in the upper air circulation with a trough development over the western United States and ridging in the eastern section of the country. This led to exceptional winter warmth in the eastern United States.

The general description of conditions over the Pacific Ocean as a whole as described by Namias and Dickson agrees with the paper by Eber who has summarized the monthly sea surface temperature charts published by the Southwest Fisheries Center. His analysis also shows generally cold conditions over the North Pacific except for somewhat warmer than normal water northeast of Hawaii in the latter part of the year.

Johnson, McLain and Nelson have provided a brief description of sea temperatures at "index stations" and also have examined time series at these stations over the past 25 years. At 30 index stations examined north of the equator, 21 were colder in 1974 than the 1948-67 mean, although, when examined in a historical context, the anomalies are relatively small. Their analysis of long term trends at these "index stations" suggest that, in general, over the last quarter of a century the surface waters of the Pacific in northern latitudes have undergone a cooling trend as have the waters off the Central American coast.

At the El Niño Symposium at the Eastern Pacific Oceanic Conference, Lake Arrowhead, October 1974, Quinn predicted a minor El Niño in early 1975 based on his studies of variations in atmospheric pressure differences between Darwin and Easter Island which are part of variations in the overall atmospheric circulation commonly called the Southern Oscillation. In his paper Quinn describes the procedure used in reaching his forecast of the El Niño. It would seemingly be a highly unusual event for another El Niño to follow so closely on the heels of the one in 1972-73. Nevertheless, the prediction by Quinn seems to have verified;

sea surface temperature between the Galapagos Islands and the mainland of South America changed from -6°F anomaly in October 1974 to +6°F anomaly in April 1975. Sea temperature did not change, however, in the area of the large anchoveta fishery off Peru which may be a characteristic of certain weak El Niños.

Upwelling may be the most important oceanic and coastal process affecting the abundance and distribution of fishery resources. Scientists have known for years that, in a gross sense, high upwelling areas are endowed with abundant fishery resources. It has been difficult indeed, however, to determine annual variations in upwelling and to relate changes in fish populations to these variations. Bakun has now developed an index of upwelling which he describes in his paper presented herein and in previous work. His chart of percentiles of upwelling index values suggest that 1974 was a very strong upwelling year at stations at 36°and 39°N latitude off central California. Conversely, downwelling was especially evident in the general region in the Gulf of Alaska.

Whereas most papers described above focused on conditions at the sea surface and in the overlying atmosphere, Saur has examined subsurface temperature structure, as well as surface temperature and salinity data. His observations were collected from "ships of opportunity," mainly along a transect from San Francisco to Hawaii. On most of this track the heat content of the upper 100 meters of the ocean was greater in 1974 than in 1973, except that it was much colder near the California Coast during the summer of 1974. These facts show that the surface warm pool northeast of Hawaii mentioned by Namias and Dickson and by

Eber extended well below the surface, and confirms strong summer upwelling around 36°N latitude suggested by Bakun's upwelling index. From the surface salinity maximum Saur also infers that the center of the Eastern North Pacific Central waters shifted to the northeast in 1974 as compared to 1972 and 1973. The shift was accompanied by lower salinity near Hawaii suggesting greater penetration of California Current Extension waters, and by less well defined boundaries and weaker fronts associated with the Transition Zone, which lies between the Eastern North Pacific Central water and the California Current waters.

What then can one say about the relation of living resources to the environment in 1974?

At the base of the food chain, that is the production of phytoplankton, one can infer from Bakun's high upwelling index off Central California in work not yet published, that plankton downstream and some time later was probably high also. Furthermore, this work suggests higher abundance of eggs and larvae of certain fish species. Future reports of The Environment of the United States Marine Fisheries Resource will describe this relationship in some detail.

The climatic change of rare proportions that affected the Southeastern Bering Sea region in the early 1970's caused serious perturbations in a number of fisheries including two of the most important species, halibut and salmon. This climatic change is described by McLain and Favorite as a result of persistent northerly winds over the area which are a result of shifts in the upper air circulation. The northerly winds caused changes in air and sea temperatures, extent of ice cover, and changes in the abundance and growth of salmon and halibut. Conditions in the winter of 1973-74 continued cold, became warmer than normal in summer 1974 and again reverted to very cold in the winter, 1974-75.

Laurs describes the early distribution and apparent abundance of the albacore tuna in relation to Transition Zone waters and associated oceanic fronts. The Transition Zone is defined as a region of mixing in the mid-latitudes between low salinity subarctic waters to the north and warm, saline subtropic waters to the south. In June of 1974 the frontal structure in the Transition Zone was more diffuse than at the same time the previous two years; consequently, in 1974 the early season albacore catches were more scattered than in 1972 and 1973.

Miller has examined the 1974 purse seine fishery in the eastern tropical tuna fisheries in relation to sea surface temperatures. In 1974 nearly 86% of all successful purse seine sets occurred in water with surface temperature between 79°F and 84°F. Less than 10% successful sets were in water temperature less than 79°F and 4% in water temperature greater than 85°F. This agrees well with findings of others who have studied purse seining success in relation to sea surface temperatures. He points out that studies to the present time have not found significant relationships between sea surface temperatures and abundance of yellowfin tuna in selected areas of the eastern tropical Pacific.

Although Barkley's paper does not specifically pertain to 1974, it is of such fundamental importance to understanding the distribution of skipjack that it is included here. Experiments carried out at the

Southwest Fishery Center, Honolulu Laboratory, suggest that skipjack should inhabit water with oxygen content in excess of 3.5 mil/liter and temperatures between about 18°C and an upper limit for their size and activity. Thus the oxygen requirement appears to be limiting the maximum habitat depth in the equatorial Pacific Ocean, whereas, in higher latitudes, low temperature appears to be the limiting feature. He points out that location and extent of areas unfavorable for skipjack probably vary with season and from year to year depending upon mixing and advection and thus winds and currents.

Atmospheric climatology and its effect on sea surface temperature.

Jerome Namias* and Robert R. Dickson**

In 1974, the atmospheric circulation over the Pacific, North American and Atlantic sectors showed certain major abnormalities peculiar to that year, yet retained other characteristics which were in keeping with the established trends of recent climatic change.

The mean annual distributions of 700 mb height and its anomaly (Fig. 3.1) show that the year as a whole was characterized by extreme strength of the mid-latitude westerlies over a broad belt of the northern hemisphere from the west Pacific to the east Atlantic. In both oceans the subpolar lows were intense (mean annual 700 mb heights 90-110 feet lower than normal), and these cells were coupled with subtropical anticyclones of almost equal intensity (mean annual 700 mb heights 70-100 feet higher than normal). This parallel increase in the vigour of the North Pacific and North Atlantic oscillations, and the high index circulation which resulted over both oceans, led to predominantly mild conditions over North America and Europe. In eastern North America this mildness was partly a direct result of the warm, moist southerly

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airstream circulating around the western flank of the strengthened Bermuda High, but more generally to the rather "flat" circulation which prevailed over North America precluding deep penetration of the U.S. by cold Canadian air masses. This weakening of the zonal flow shown in the mean annual circulation over North America is at least partly attributable to the effect of the Continental Divide operating on the strong Pacific westerlies.

The mean annual distribution of Pacific sea surface temperature (SST) anomaly (Fig. 3.2) was the expected reflection of the high index circulation in that sector. Across the northern North Pacific, in the domain occupied by the strengthened Aleutian Low, a broad belt of abnormally cold water with a core anomaly of <-1.7°F underlay the area of enhanced westerlies, cyclonicity, cold-frontal activity and Ekman divergence with open-ocean upwelling. To the south a zonal pool of warm water with temperature anomalies in excess of +1.1°F reflected the light winds, clear skies and horizontal oceanic convergence associated with the intensified subtropical high, though northerlies running along the eastern flank of this cell maintained cooler conditions locally along the North American seaboard.

While equivalent data are not yet readily accessible for the Atlantic as a whole, the available SST data for the western Atlantic (U.S. Naval Oceanographic Office, 1973-74) show a rather uncomplicated development throughout 1974, readily explicable in the light of the dominant circulation anomaly in that area. Seasonal variations will be discussed more fully below, but the seasonal charts of SST anomaly distribution shown in Fig. 3.3a, b, c and d indicate that abnormally warm water conditions prevailed throughout the year in the Atlantic west of 55°W. Again the cause is attributed to the warm southerly anomaly wind prevailing along the western flank of the strengthened Bermuda High, lessening the transfer of sensible and latent heat from the ocean, while the anticyclonic cell itself was positioned to minimize the deep out-breaks of polar continental air from North America to the western Atlantic during the cold season.

Needless to say, this interpretation of "mean annual" charts provides a deceptively simple impression of climatic developments in ocean and atmosphere. This approach has a validity in indicating the dominant residual climatic controls at work in a particular year but will conceal the existence of seasonal or monthly variations which may run counter to the overall climatic trend. Equally it ignores the influence of antecedent conditions which may be of great importance in understanding the development of temperature variations in the ocean. To give one example, the cold surface temperature conditions in the west and northwest Pacific became established as early as the December 1972 and indeed Wagner (1975) pointed out that 1974 was the fourth consecutive year in which the winter atmospheric circulation was stronger than normal over most of the western half of the Northern Hemisphere. These antecedent trends of change are discussed more fully below.

As regards seasonal variations within 1974, Fig. 3.4 (from Wagner, op. cit.) shows that while the mid-latitude westerlies were generally strong throughout 1974 the strongest zonal index was principally a feature of winter and spring with an absolute maximum in February. In that month they represented "the strongest mean westerlies between 35°N and 55°N over the Western Hemisphere for any February since tabulations began in 1949. It was the second highest monthly mean mid-latitude westerly zonal index (13.3 m/s) of record - only January 1972 had stronger westerlies (13.9 m/s). At their peak near 43°N the westerlies averaged 6 m/s above normal" (Wagner, op. cit. p.29). As indicated in Fig. 3.4, westerlies 5 m/s stronger than normal persisted through April and May, and even in summer and fall mean windspeeds 2 m/s in excess of normal were rather commonly observed.

The seasonal mean distributions of 700 mb height anomaly for winter and spring (Fig. 3.3a and b) confirm the extreme strength of westerlies in these seasons, but provide additional information on their geographical distribution and on the timing of peak zonal wind strength. It is clear that the enhanced westerlies were chiefly a feature of the ocean areas, and although, on a "Western Hemisphere" average, they reached maximum intensity in February, they attained (on aggregate) a seasonal maximum in winter over the western Atlantic but in spring over the eastern Pacific. In winter the anomalous north-south height difference in the 700 mb surface at 55°W was in excess of 330 feet (-170 to +160 feet), while in spring the peak anomaly in the meridional direction exceeded 300 feet (-220 to +80) in the eastern Pacific (at 150°-170°W). The seasonal distributions of

SST anomaly, also shown in Fig. 3.3a and b, reflect these differences in the timing of maximum zonality over the two oceans. Under the western flank of the intense Bermuda High, surface temperatures reached a peak seasonal mean value of +5.1°F in winter, and temperature anomalies in excess of +2°F were more widespread along the Atlantic Coast than at any other season of 1974. In the eastern Pacific sea surface temperature anomalies became organized into a more extreme zonal distribution as the westerlies strengthened from winter to their maximum in spring.

In summer (Fig. 3.3c) events in the western Atlantic were dominated by the partial collapse of the Bermuda anticyclone and by the lowering of positive SST anomalies which resulted. In the eastern Pacific, however, the situation was much more complex and the seasonal distributions of SST and 700 mb height shown in Fig. 3.3c were overwhelmingly a reflection of an extremely abnormal development in the month of July. In that month the sudden intensification of a trough off the coasts of Oregon and British Columbia was accompanied by a major amplification of a ridge centered to the north and east of Hawaii. These cells represented anomalies in the 700 mb surface of 1.7 and 3.1 standard deviations respectively. The seasonal distribution of 700 mb height shown in Fig. 3.3c provides only a week reflection of this development, but its effect is perhaps more clearly reflected in the seasonal distribution of SST anomaly. Along the maximum pressure gradient a family of storms was guided in to the Pacific West Coast at a southerly latitude (40-45°N) where storms are rarely observed in mid-summer (see Anon, 1975 Fig. 37) bringing 1-2" of rain to areas which are usually practically rainless at that time of year. In his statistical analysis of the principal tracks and mean frequencies of storms in the northern hemisphere, Klein (1957) showed that during 40 Julys, 1899-1938, there was a total of only one to three days when a low pressure center of any type was encountered at these latitudes on the west coast, since the area is normally dominated by the summer expansion of the North Pacific subtropical anticyclone. The effect of this series of storms on Pacific surface temperature was striking, with an anomaly of -4°F developing rapidly along their track (see Eber and Miller, 1974, Fig. 3.5), and this "corridor" of cooling was sufficiently intense to dominate the seasonal distribution of SST anomaly, (Fig. 3.3c).

The factors which gave rise to the unusual circulation of July are unexplained but are certainly complex. While the cold sea surface temperatures in the northeastern Pacific in antecedent months (Fig. 3.3b) may have been (to some extent) effective in bringing about a hydrostatic deflation of the overlying air column, and hence may have played some part in deepening the offshore trough in that area, it is likely that remote influences also played a major, perhaps even the dominant, role in causing the intensification of this cell. A rapid amplification of a trough off Asia (along 165°E) was also observed in July and this event may be expected to have had some effect on the development of an augmented ridge to its east and a trough in the eastern Pacific. However that may be, this circulation itself had a more than local importance in that a falling away of pressure in the eastern Pacific in summer and a relative tendency towards ridging in mid Pacific is characteristically associated with a drought-producing circulation over the U.S. This case proved to be no exception, and resulted in the "worst heat wave and drought since the 'Dust Bowl' summers of the 1930's" at many localities in the northern and central Great Plains, (Wagner, op. cit. p. 33). Drought conditions were subsequently relieved in August as the mid-latitude atmospheric circulation of the Western Hemisphere showed an almost complete reversal from that of July. This in itself is a rather unusual event serving to underline the anomalous nature of the July circulation; Namias (1952, p. 281) showed that over North America the month-to-month persistence of climatic anomalies is normally near its peak between July and August.

This reversal of the circulation in August resulted in the domination of the north eastern Pacific by a high pressure anomaly cell which maintained its identity into the fall (Fig. 3.3d). As might be expected the southerly airflow, clear skies and light winds associated with this cell encouraged the spread of relatively warm water northwards into the Gulf of Alaska. The complete change in circulation patterns between summer and fall (cf. Figs. 3.3c and d) brought an extensive meridional trough to northeast Canada in place of the pre-existing ridge. Enhanced northerly airflow between this cell and the newly-formed ridge over the west coast brought cooling to the entire North American continent east of the Rockies during fall. Wagner (op. cit. p. 34) showed that September, with temperatures as much as 10°F below normal over Texas, was also the coldest of record at several cities in the southern and central Great Plains and Mississippi Valley. Although in the seasonal average, this enhanced northerly airflow was directed from the Arctic towards the Atlantic coast states, the trough was not of sufficient meridional extent to produce extensive cooling in the already-warm surface waters of the west Atlantic. Instead, with the southern flank of this trough lying along the Canadian Maritime Coast and with a restrengthening Bermuda High offshore, an intensified southerly airflow brought renewed warming to the Western Atlantic; colder-than-normal sea surface temperatures were limited to a restricted area in New York Bight where the northerly airflow from the Canadian Arctic retained some effectiveness.

As mentioned earlier, a full understanding of the evolution of the ocean surface temperature distribution relies partly on a knowledge of antecedent atmospheric and oceanic conditions, and it is the purpose of this final section to set these 1974 observations into the context of longer-term climatic change. In Figure 3.5 the mean SST anomalies in zonal bands of 5° x 5° squares running offshore from the west and east coasts of North America have been plotted for each month of the period January 1969 to November/December 1974, and the resulting "sections" of SST anomaly versus time have been contoured at 2°F intervals. Cooler than normal surface temperatures are shown by cross-hatching, and the core values of anomaly are plotted on each section.

The SST anomaly section for the Pacific captures the major changeover in SST pattern which occurred between the 1960's and 1970's already by Namias (1972). Prior to 1971, SST anomaly patterns (especially in winter) were characterized by anomalously warm water off the west coast of the United States and cold water in the Central Pacific, but subsequent winters have tended to show the opposite pattern with cold water off the west coast and warm water further offshore. Thus abnormally cold surface temperature conditions were already present in the northeast Pacific prior to 1974 and the cold conditions observed throughout the section in 1974 represent merely a reinforcement of earlier cold conditions by the strongly zonal circulation in that year.

This major changeover in the SST patterns of the eastern Pacific was accompanied by, and is thought to have assisted in the development of, a major break in the atmosphere circulation over continental North America such that a stronger-than-normal ridge in the long wave over western North America and an intensified trough over the east were replaced by a circulation of the opposite tendency, most noteably in winter. (The reverse circulation change had in fact occurred in the winter of 1957-58 so that the changeover in 1971-72 represented merely a revision to the characteristic winter circulation pattern of the period 1948-57). In the specific area of the Atlantic seaboard the circulation change after 1971 (with a weakening of the pre-existing trough over eastern North America and a strengthening of the Bermuda High) led to conditions of exceptional winter warmth, and indeed the SST anomaly section for the Atlantic shown in Figure 3.5 reflects this change in showing a general warming of the ocean surface along the Atlantic coast in winters subsequent to 1971. Thus the warm conditions prevailing offshore throughout 1974 were also based partly on antecedent warm conditions, though the exceptional strength of the Bermuda anticyclone from the fall of 1973 produced an exaggerated development of this general warming trend.

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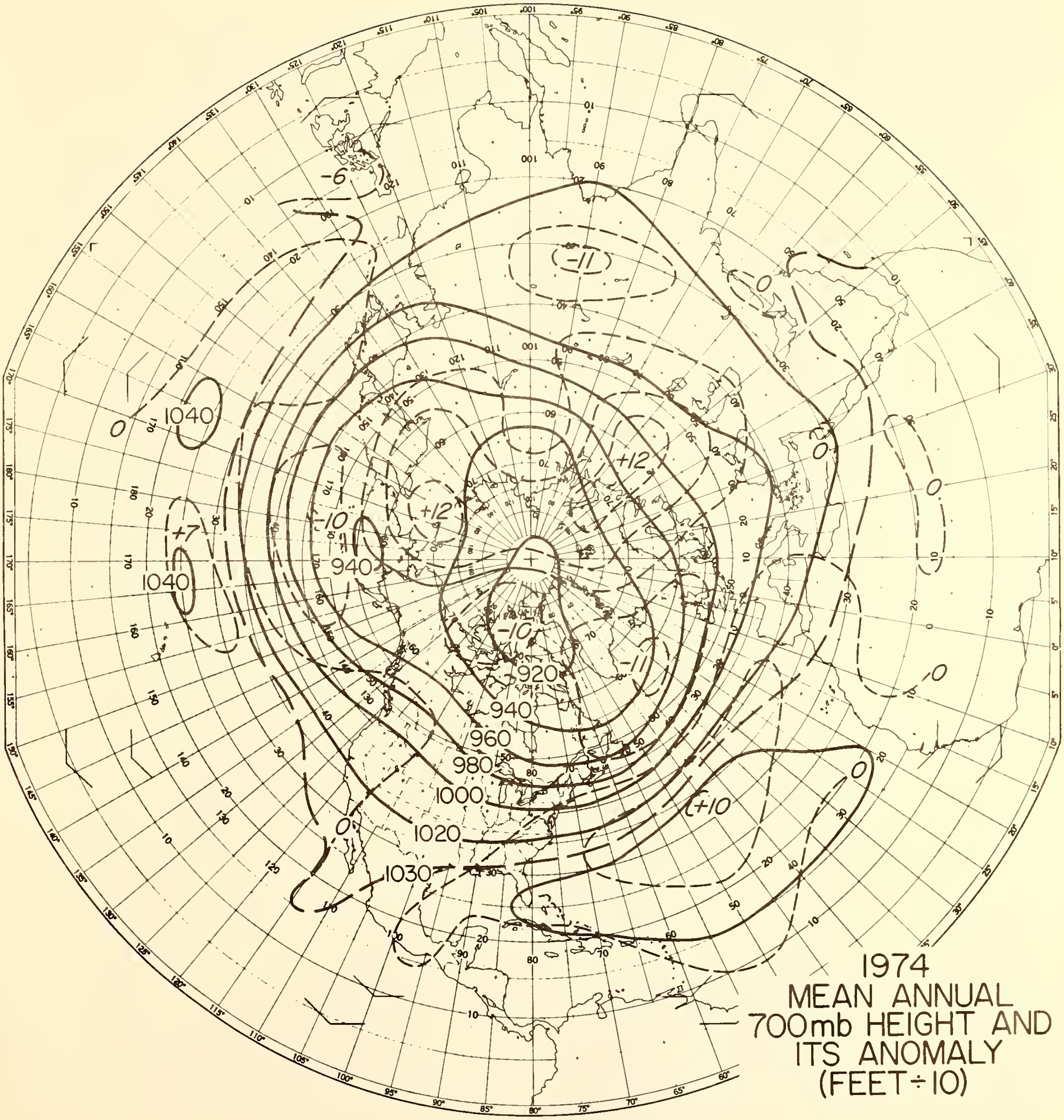

Figure 3.1 Mean annual distribution of 700 mb height and its anomaly, 1974. (Feet ÷ 10)

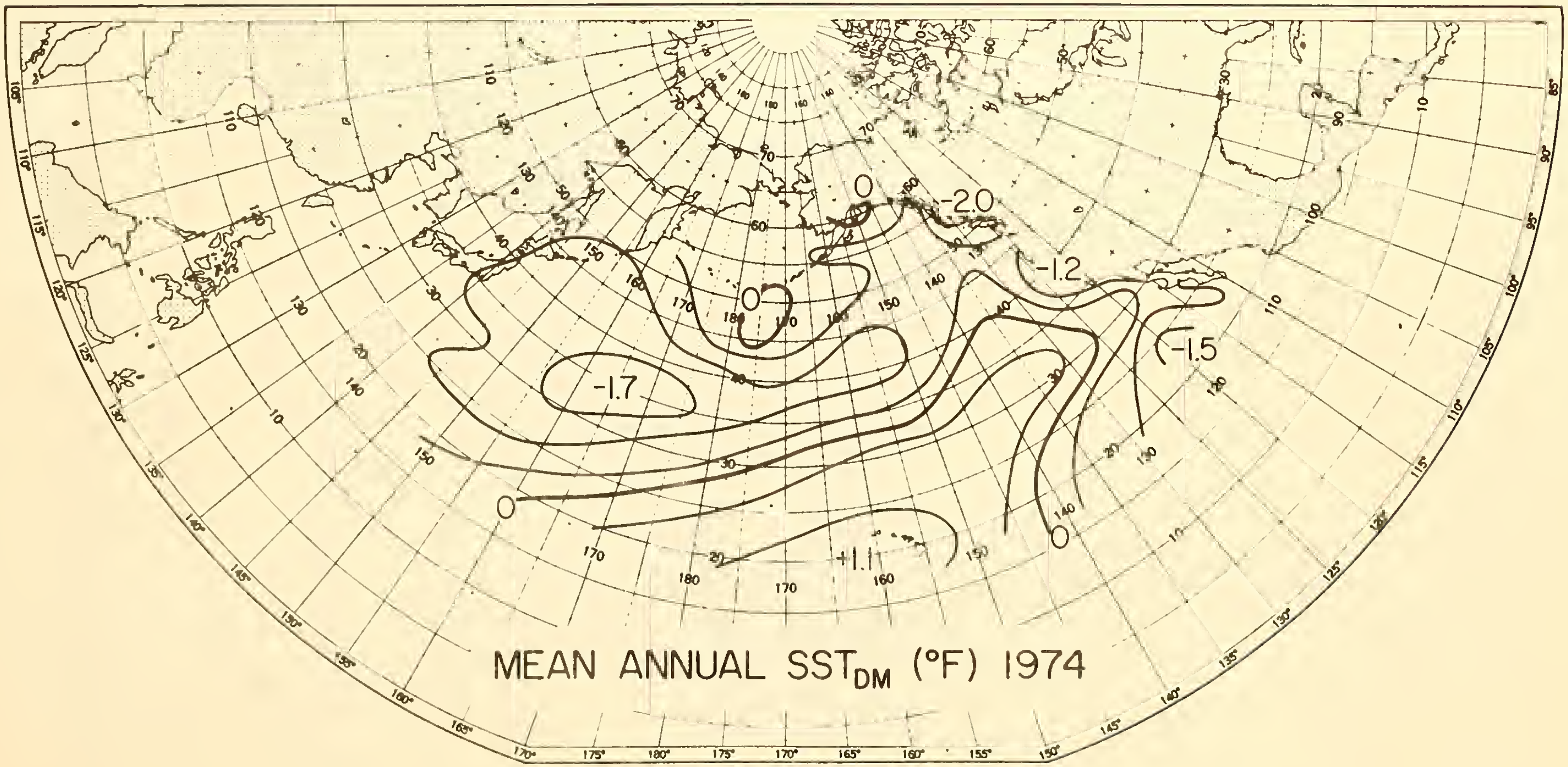

Figure 3.2 Mean annual distribution of Pacific SST anomaly in 1974, contoured at intervals of 0.5°F.

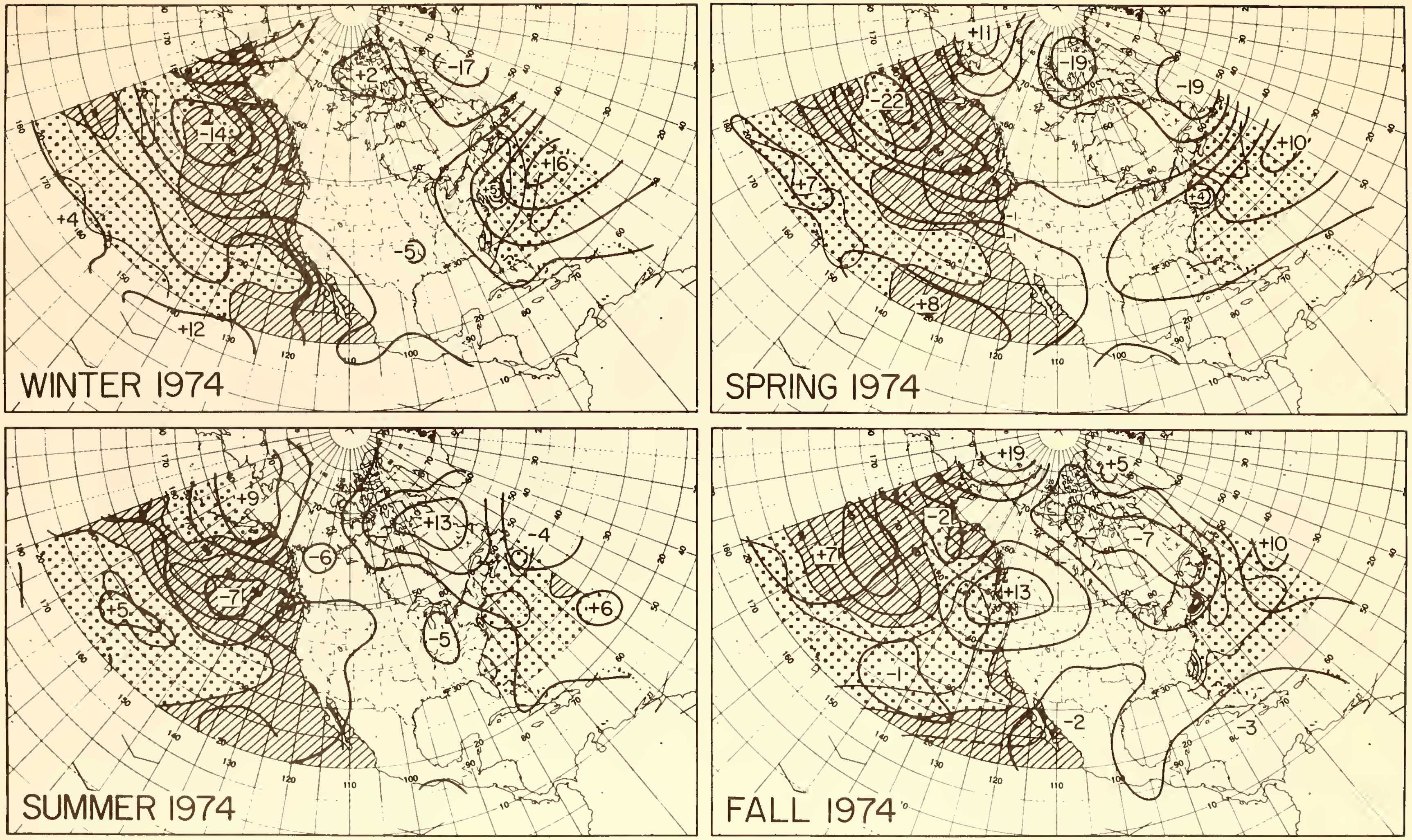

Figure 3.3 Mean distribution of 700 mb height anomaly (feet ÷ 10) for the seasons of (a) winter (b) spring (c) summer and (d) fall 1974 (heavy solid lines). Mean seasonal distributions of SST anomaly for the eastern Pacific and western Atlantic are also shown, contoured at intervals of $1^{o}F$ (lighter solid lines). Areas of positive SST anomaly are stippled, and areas of negative SST anomaly are cross-hatched.

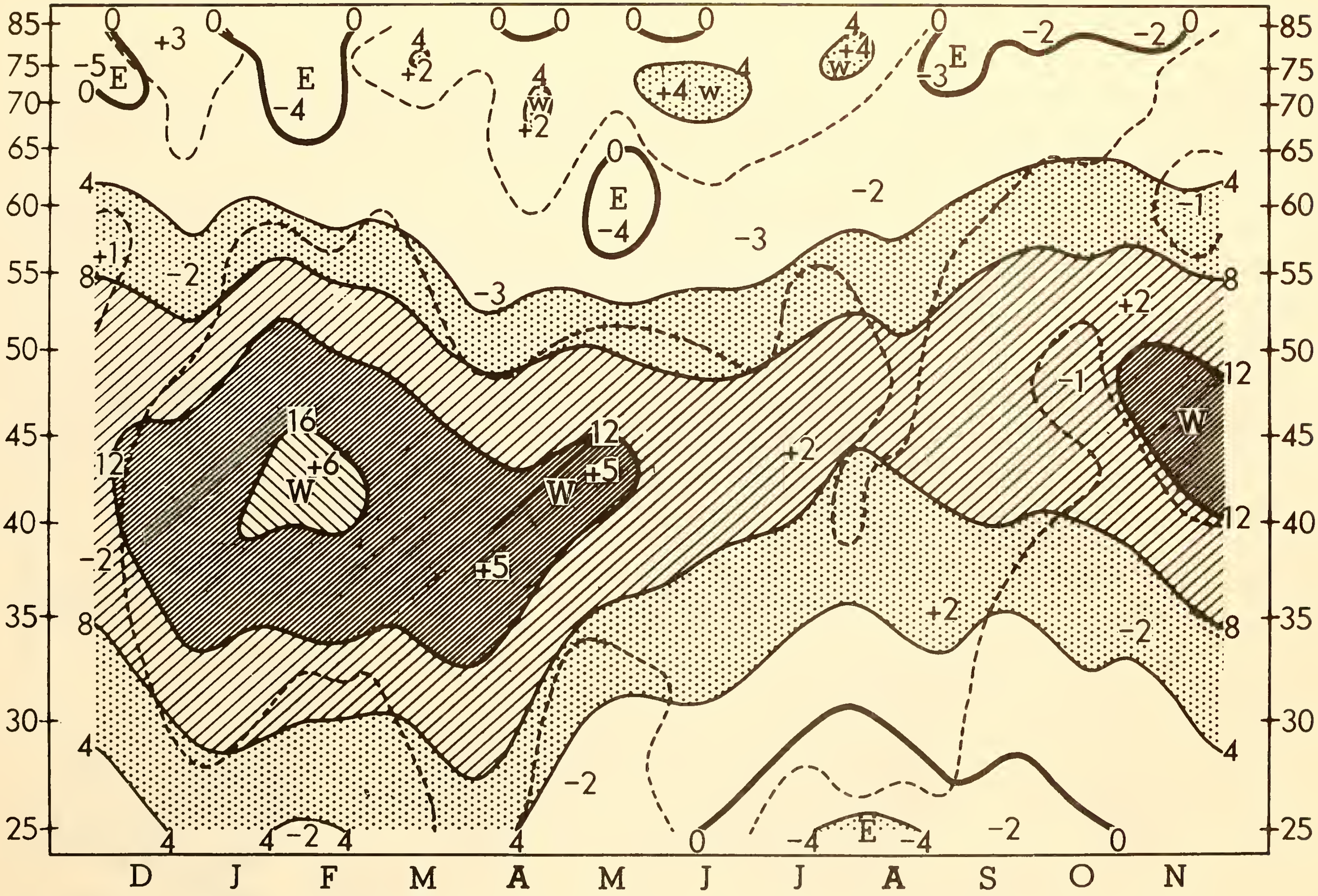

Figure 3.4 Variation of monthly mean 700 mb wind between latitudes 25°N and 85°N over the Western Hemisphere (0°-180°W) from December 1973 to November 1974. Solid contours show the westerly or easterly component of mean geostrophic wind (m/s) with areas of maximum westerly or easterly wind indicated by W or E respectively. Numbers with signs show locations of greatest departure from the normal, with normal areas connected by dashed lines. From Wagner, 1975.

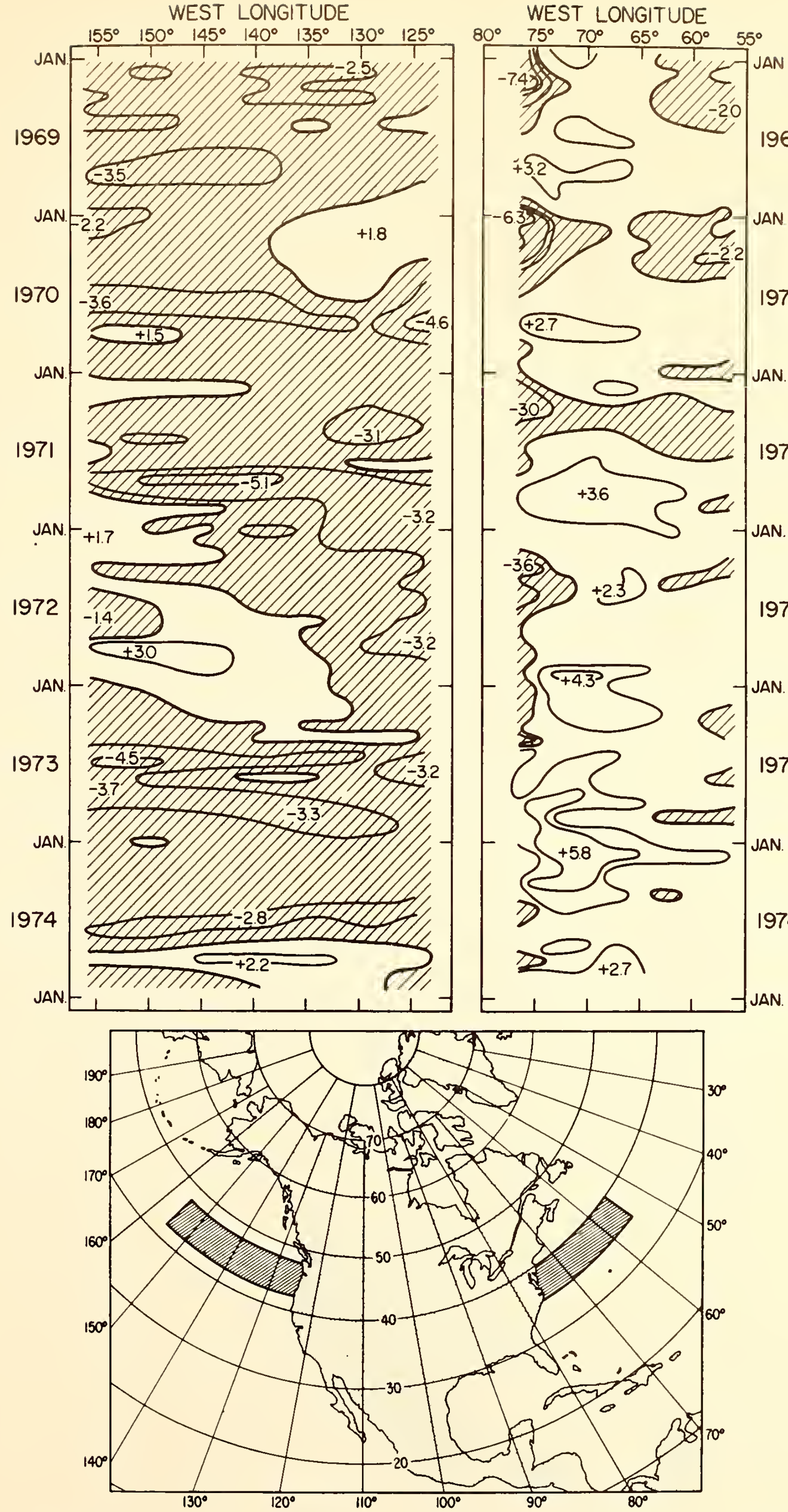

Figure 3.5 Temperature "sections" for zonal bands of $5^{\circ} \times 5^{\circ}$ squares running offshore from the west and east coasts of North America. In each section the mean SST anomalies for each $5^{\circ} \times 5^{\circ}$ square have been plotted for each month of the period January 1969 to November/December 1974, and are contoured at intervals of 2°F. Areas of negative SST anomaly are shown by cross-hatching and the core values of anomalies are plotted on each section. A location chart is also shown.

CLIMATIC CHANGE IN THE PACIFIC OCEAN

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INTRODUCTION

Over the past fifteen years the National Marine Fisheries Service and its predecessor the Bureau of Commercial Fisheries have published sea surface temperature and anomaly charts of the Pacific Ocean. These charts have been used by the fishing industry in development of fishing strategy (Felando 1966), by marine scientists studying changes in distribution of marine resources (Laurs 1975) and by those studying large scale air-sea interactions in relation to long range weather forecasting (Namias 1972; Quinn 1972).

It is becoming increasingly clear that some fish populations may respond not only to short term changes in the environment, but also to long term climatic change. As a complement to the ongoing effort of the publication of sea temperature charts, this report and ensuing annual reports of "The Environment of the United States Living Marine Resources" will examine climatic changes for use in fisheries research and other related studies.

This study provides time series of sea surface temperature for 33 selected 5° blocks of latitude and longitude in the Pacific Ocean (Figure 4.1) where abundant observations of sea surface temperature are available historically. The blocks are identified in this report

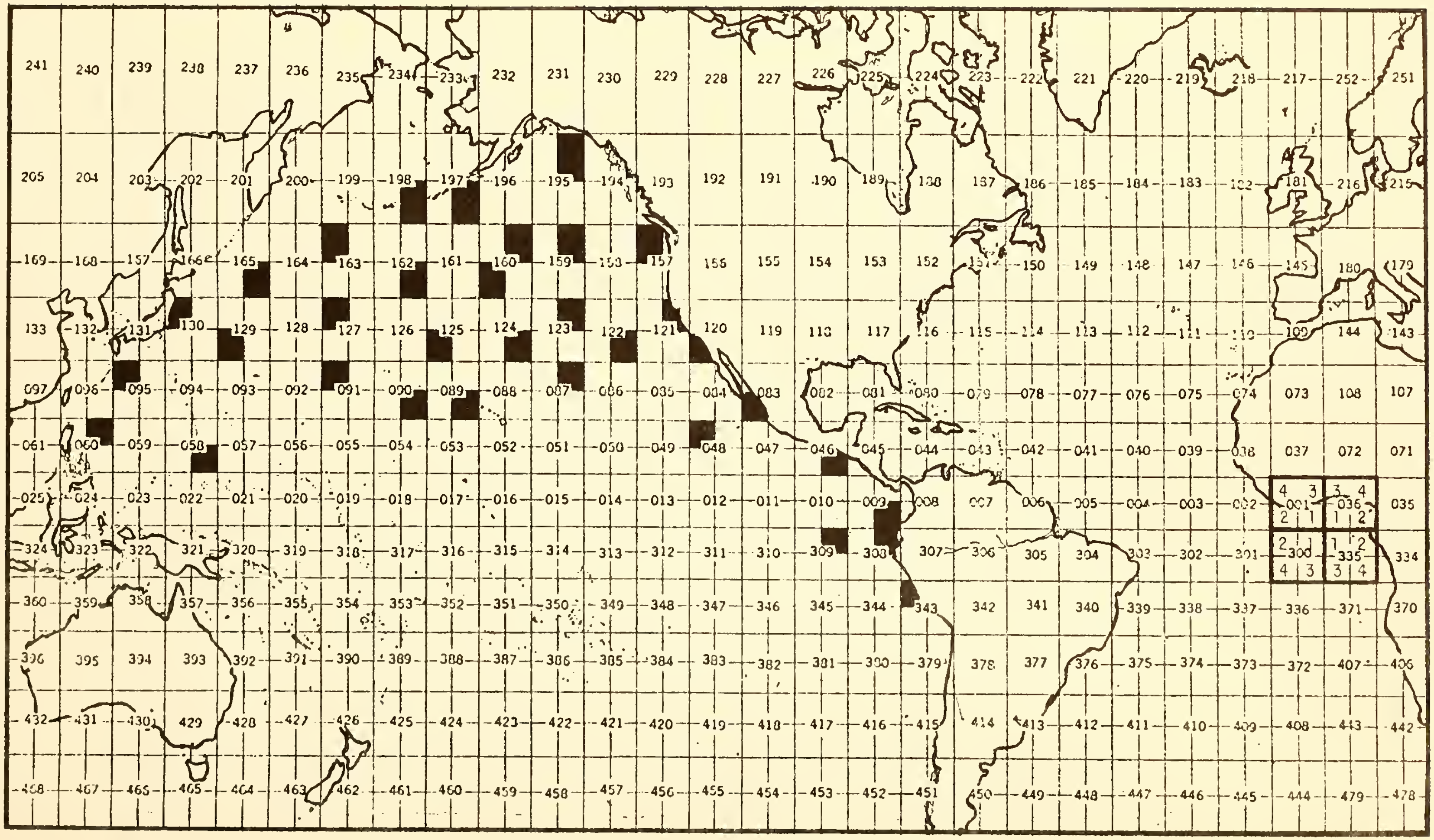

FIGURE 4.1 INDEX STATIONS, PACIFIC OCEAN. NUMBERING OF QUADRANTS WITHIN MARSDEN SQUARES FOR THE FOUR QUARTERS OF THE GLOBE IS SHOWN IN THE INSET. NOTE THAT NUMBERING SEQUENCE CHANGES AT THE INTERSECTION OF THE EQUATOR AND PRIME MERIDIAN.

by Marsden Square number and quadrant of the Marsden Square and are referred to as "index stations." Since most such observations were made by merchant or naval vessels, the index stations generally lie along shipping routes.

Also included is a composite of 5° blocks showing the trend in sea surface temperatures over the entire North Pacific for summers, winters and annually.

DATA SOURCES AND PROCESSING

The time series of sea surface temperature were derived from weather reports from merchant, naval, and other ships of many nations. Several files of such reports were used to develop the series. A historical file of reports covering the period 1854 to June 1968 was obtained by Fleet Numerical Weather Central from the National Climatic Center. An update to this file was subsequently obtained by the North Pacific Experiment (NORPAX) Project at Scripps Institution of Oceanography and included reports to December 1972. These files were merged, sorted by 1° blocks, duplicate reports eliminated, and monthly means of all reports of sea surface temperature in the selected 5° blocks developed.

Weather reports received in "real-time" by Fleet Numerical Weather Central by teletype were used to update the series through 1974. Monthly means of these reports were made for the period November 1971 to December 1974. These means were used during 1973 and 1974 and occasionally during November 1971 to December 1972 whenever more real-time reports were available than were available from the historical files.

Various sources of errors associated with the means of sea surface temperature are as follows:

1) Due to the need for ships to avoid areas of bad weather, the original observations are biased towards fair weather conditions. This bias has become more important in recent years as marine weather reporting, forecasting, and optimum track ship routing have improved.

2) The observations are not randomly distributed over large ocean areas but instead are concentrated along various shipping lanes. Thus observations are much more dense off Japan and California than in infrequently traveled portions of the South Pacific Ocean. Also the data are biased due to varying distribution of observations in time and space within each 5 degree block. This error may be particularly significant where the sea surface temperature changes rapidly in time or space.

3) Most of the observations of sea surface temperature are "injection temperature," that is, they are made with a thermometer in the ship's main cooling water intake. Thus they are subject to instrument calibration error and to warming of the intake water in the engine room. Saur (1963) studied these errors and found that the injection temperatures in the class of ships he studied averaged about 1.2°F higher than surface water temperatures taken by a bucket thermometer.

All reports of sea surface temperature were edited by a two stage editing technique prior to development of the 5° block means. The first stage of editing rejected all observations that were less than -2.0°C or greater than +40.0°C to eliminate obviously erroneous values. The second stage of editing differed slightly for the historical and real time data.

For the historical data, running means of 10 reports were maintained for each of the 12 months and each report was compared with the appropriate running mean. Values greater than 9°C from the running mean were rejected. Because the data had been sorted in the sequence: 1 degree block, year, and month, the running mean contained only observations for the month in question and at worst observations from several previous years. The running means were restarted for each new 1 degree block using the 10 earliest reports available (starting as early as 1854). Monthly means were computed by 5° blocks from the accepted reports, and from these a 20-year (1948-1967) mean computed for use in editing of real time reports and for use in computation of anomalies. Generally there were 19 or 20 years of data in the 1948-67 mean. The lowest number of years represented at any one index station was 14 at station 195-3.

In editing of real time reports, values greater than 10°C from the 1948-67 mean were rejected.

The monthly means were stored on a summary data tape from which the time series plots were made. Though data are available at some stations back to 1854, some of the early reports may be of questionable accuracy. In addition, the early data were sparse and at most stations insufficient for analysis until about 1948 and 1949. Time series were prepared, therefore, only for the period 1948 or 1949 to 1974.

Marine organisms may be most sensitive at the extremes of temperature ranges, that is, to extreme cold and warm temperatures. To detect these extremes of temperatures, we present time series not only as annual means but also as winter (January, February and March) and summer (July, August, and September) means. (See Appendix I for time series plots).

DISCUSSION

A. Method used to calculate trends

Non-random variations in time series of sea surface temperature take the form of periodic or aperiodic fluctuations, persistence, trend, or a combination of these. Seasonal periodicities are evident in the time series of sea surface temperatures throughout most of the north Pacific. However, these data also indicate significant longer term climatic trends which appear to be coherent over large areas.

Although there is no reason to believe that trends in climatological time series are linear (Mitchell et al. 1966), a test for trend against randomness may provide an approximation of the warming or cooling indicated by the data.

Results from this analysis specifically apply to the 27-year data record from 1948 to 1974. We have not attempted to resolve shorter term fluctuations which may be evident in the data, nor do we imply that these results can be extrapolated in time. It is probable, however, that significant climatic changes, such as the recent pronounced cooling trend in the Gulf of Alaska, have important long term effects on the biota.

An analysis of trend against randomness was considered for time series of monthly mean sea surface temperature summarized by five degree blocks for the 27 years from 1948 to 1974. Missing data were filled with appropriate 20-year (1948-1967) long term monthly means. Time series containing more than 3 years (36 months) of missing data were not considered in the trend analysis, which was applied to time series of annual means, winter means, and summer means computed from the monthly mean data.

Linear trends for the 27 year time series (annual, winter, summer) were computed in the least squares sense as described by Bendat and Piersol (1971, p. 291). The slope of the regression line was considered to be a first order approximation of the magnitude of the warming or cooling tendency. A Mann-Kendall rank statistic (Mann 1945; Kendall 1948) was computed for each time series. The sign and magnitude of the computed rank statistic indicates the sign and magnitude of the trend. Comparison of the computed statistic with a Gaussian (normal) distribution substantiates the presence of (linear or non-linear) trend in the data, or indicates that the data series is random.

B. General areas of most highly significant trends

The most significant trends over large areas in the northeast Pacific appear particularly in the Gulf of Alaska (Marsden squares 194, 195, 196 and 197) and off the coast of Mexico (Marsden squares 47, 48) (Figure 4.2, 4.3, and 4.4). The cooling trends of approximately 0.02°C/year to 0.03°C/year are significant at the 95% level. This tendency may be partially attributed to significant cooling during the summer quarter (July, August, September). In the Western Pacific (parts of Marsden squares 129, 130, 162, 163, 164), warming trends of approximately 0.02°C/year are significant at the 90% level. This climatic change can be partially attributed to warming during the winter quarter (January, February, March).

C. Trends at selected index stations

1. Northeast Pacific

The most significant trends at specific index stations in the northeast Pacific are in the most northern latitudes. At index station 195-3 the annual mean ranged from nearly 10°C at the time of the "warm" 1957-58 years in the eastern Pacific to about 7°C in the early 1970's. The maximum anomaly of +2.7°C appears in the summer of 1957. In the region of the Aleutian Islands, index stations 197-1 and 198-1 show clearly the very cold anomalies in the early 1970's. Response of the Alaskan salmon and other fisheries to this climatic shift is explained elsewhere in this volume (McLain and Favorite 1975).

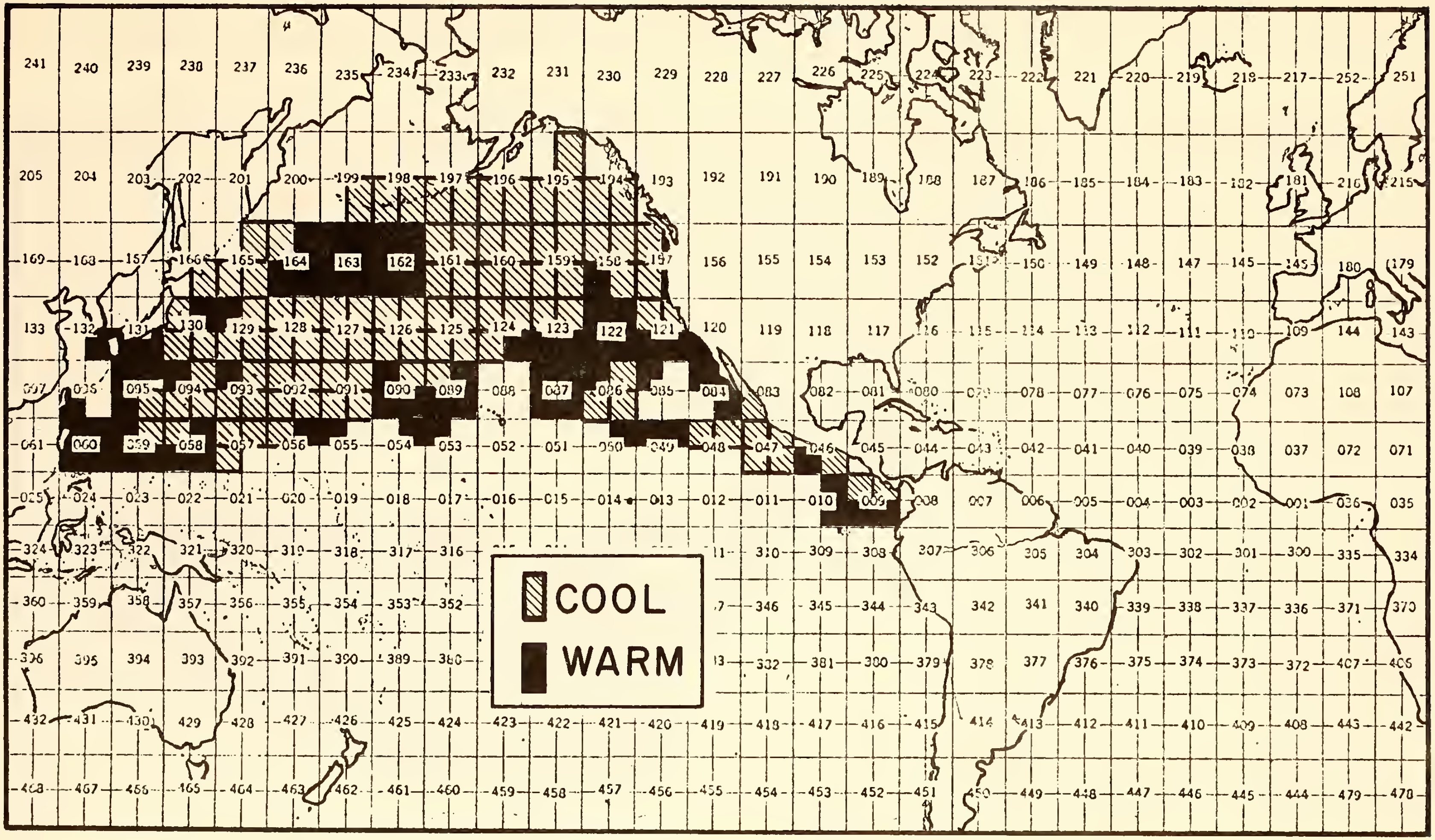

FIGURE 4.2 TRENDS IN ANNUAL CHANGES OF SEA SURFACE TEMPERATURE PACIFIC OCEAN, 1948-1974, BY 5° BLOCK. CROSS HATCHED BLOCKS DENOTES COOKING TREND, BLACK BLOCKS WARMING TREND.

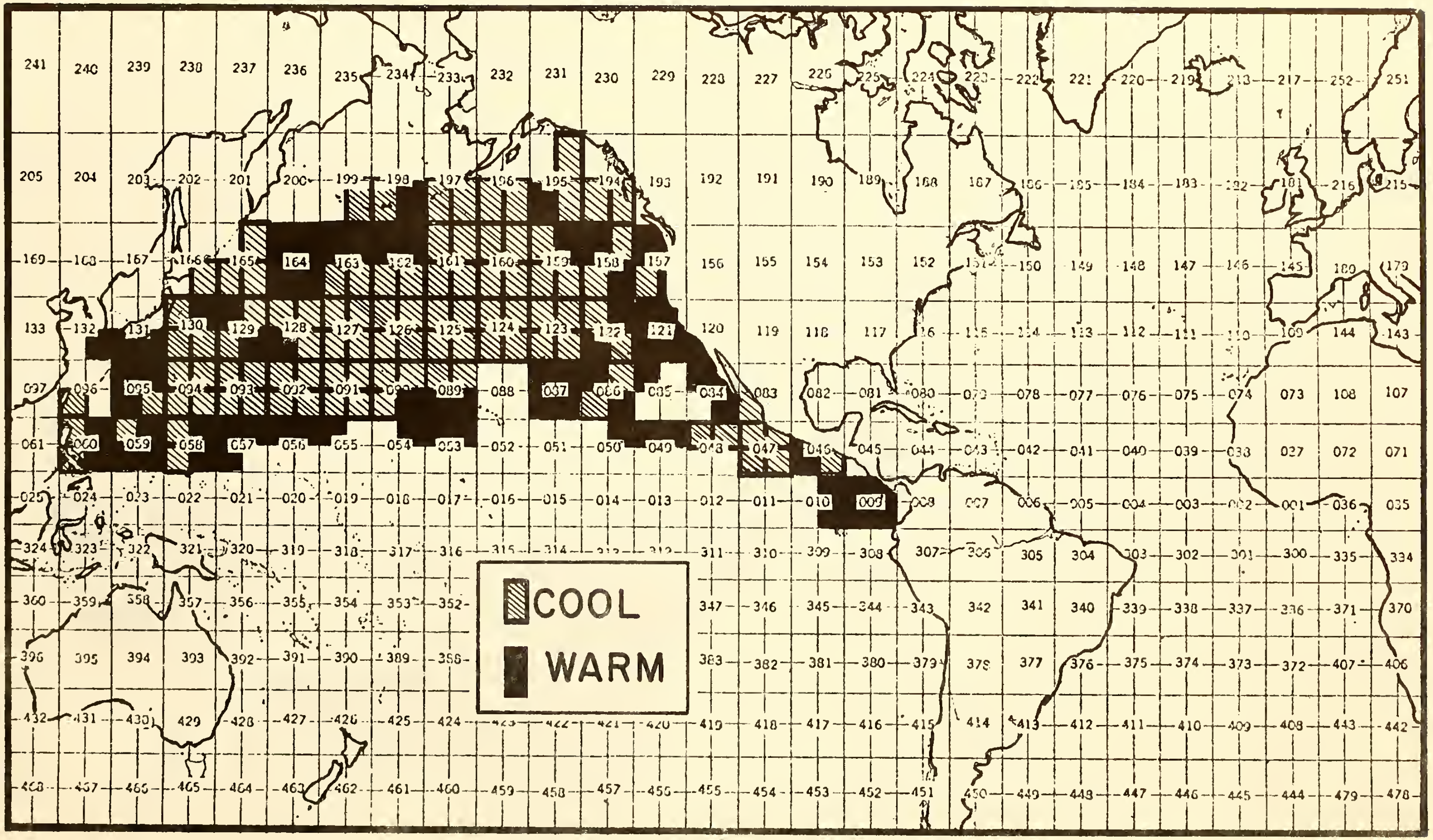

FIGURE 4.3 TRENDS IN WINTER CHANGES OF SEA SURFACE TEMPERATURE PACIFIC OCEAN, 1948-1974, BY 5° BLOCK. CROSS HATCHED BLOCKS DENOTES COOLING TREND, BLACK BLOCKS WARMING TREND.

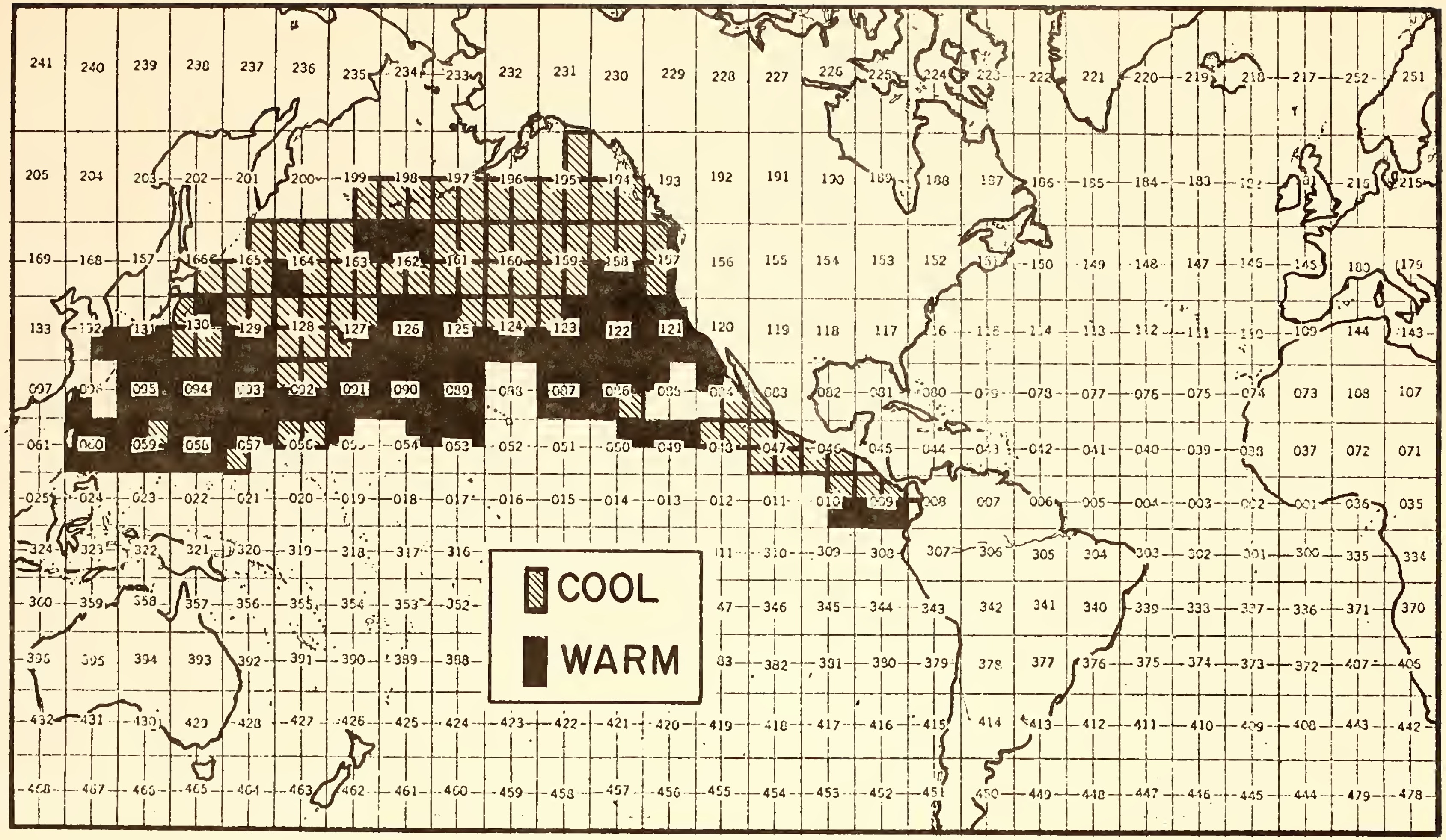

FIGURE 4.4 TRENDS IN SUMMER CHANGES OF SEA SURFACE TEMPERATURE PACIFIC OCEAN, 1948-1974, BY 5° BLOCK. CROSS HATCHED BLOCKS DENOTES COOLING TREND, BLACK BLOCKS WARMING TREND.

The very warm sea temperatures that appeared off the U.S. west coast at the time of the 1957-58 El Niño are evident at index stations 120-2 and 121-3. Response of fishery resources to this warm period is well described by Radovich (1961). Index stations 46-1, 48-4 and 83-2 indicate a long term cooling trend in the eastern tropical Pacific. This appears most pronounced in the summer. Cold anomalies are evident in nine of the last ten summers at stations 46-1 and 83-2.

A warm summer anomaly is especially apparent in 1968 in the region northeast of the Hawaiian Islands at index stations 87-3 and 122-1. The 2.0°C positive anomaly at station 87-3 is over three standard deviations from the 20-year mean. This highly significant event has been little recognized. It was first shown in the publication Fishing Information (Renner and Raymond 1968). One reason that it has not been described in more detail is that the anomaly of 2.0°C when viewed in relation to magnitude of anomalies in other regions is not conspicuously large. This is due in part to the fact that thermal gradients in regions of strong currents in many other areas are much more pronounced and a slight shift in the current can cause large anomalies. In the area northeast of Hawaii this is not so. Gradients are relatively flat and, as the time series suggests, large anomalies occur infrequently. Another reason that it has been little described is that it does not cover an area of an intense fishery. Thus, there has not been the impetus to describe this event in relation to effects on fisheries.

Namias (1971) pointed out that the formation and persistence of this large anomaly over a widespread area in the southern part of the North Pacific may have been the cause later in the year through complex air-sea interactions of abnormally high precipitation in California.

2. Northwest Pacific Ocean

Index station 130-3 in the western boundary current off Japan shows very large variations. This may be due to change in meanders of the Kuroshio and Oyashio. McLain et al.[1/] show that in the region of western boundary currents, i.e., the Gulf Stream, large anomalies can appear which are due in part to shifts in the location of the current boundaries.

3. Southeast Pacific

Stations 308-1, 309-1 and 343-2, in the area of the South American anchoveta fishery and to the west show clearly the large changes that occur off the coast of South America from year to year. If environmental change effects certain specific events in the life history of the anchoveta, and there is much evidence to suggest that it does, one can surmise from inspection of the historical sea temperature record that in the future we might expect continued perturbation to the anchoveta population caused by environmental change.

Although we do not have an index station in the equatorial region to the west of the Galapagos Islands, change from year to year in

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McLAIN, D.R., F.V. MAYO and M.J. OVEN
Monthly maps of sea surface temperature anomaly in the Northwest Atlantic Ocean and Gulf of Mexico, 1948 to 1967. Accepted for publication in NOAA Technical Report NMFS SSRF.

this area is also very large. For example, November 1972 and November 1973 sea temperature charts published by the National Marine Fisheries Service, Southwest Fisheries Center (Renner 1972; Eber 1973) show that in the latter month, sea temperatures were as much as 4°C colder than they were a year earlier.

D. Sea Temperatures in 1974

The northeast Pacific appeared, in general, to be cooler than normal in 1974 (Table 1). Of 21 index stations monitored, 16 of the annual means remained colder than the 1948-67 mean. The most pronounced anomalies appeared in the eastern tropical Pacific Ocean. The winter anomaly at the mouth of the Gulf of California (station 83-2) reached -1.5°C which was the largest winter anomaly of any index station in the northeastern Pacific. The cold anomalies in the region of the Aleutian Islands were significantly less than the very cold anomalies which were present in 1971, 72 and 73. In 1971 at station 197-1, the summer anomaly nearly reached -2.0°C. In the summer of 1974, the anomaly was +0.2°C.

In the northwest Pacific a large annual anomaly of -2.3°C (station 130-3) appeared to the east of Honshu Island. Caution must be used in interpretation of this and other anomalies in regions of strong thermal gradients such as are found in the Western Boundary currents. Small shifts or meanders in the current can cause high anomalies as was described earlier.

Table 1. Annual Mean Temperature Anomaly (°C) in 1974 at Pacific Ocean Index Stations

Northeast Pacific Ocean

5° Block	Temperature °C
9-1	-0.6
46-1	-0.5
48-4	-0.5
83-2	-0.7
87-3	+0.3
89-1	+0.4
90-1	+0.4
120-2	-0.8
121-3	-0.7
122-1	+0.4
123-3	-0.6
124-1	0.0
125-2	-0.2
157-4	-0.5
159-3	-0.6
160-2	-0.6
160-3	-0.5
162-1	-0.8
195-3	-0.8
197-1	-0.2
198-1	-0.2

Northwest Pacific Ocean

5° Block	Temperature °C
58-2	+0.1
60-4	+0.1
91-3	+0.1
95-3	+0.1
127-3	-0.6
129-1	-0.3
130-3	-2.3
163-3	-0.1
165-2	-0.7

Southeast Pacific Ocean

308-1	Insufficient Data
309-1	-0.3
343-2	Insufficient Data

The four stations monitored in the region off South America were all colder than the mean in winter. Summer anomalies were mixed.

Acknowledgment

We wish to thank the Commanding Officer of Fleet Numerical Weather Central for making data available and for use of computer facilities in analyzing the data files.

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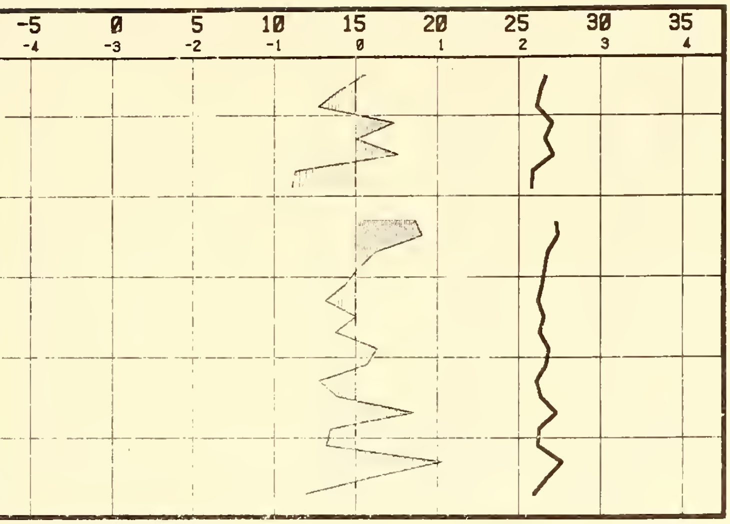
APPENDIX I

Time series plots of sea surface temperature and anomaly at 33 "index stations" in the Pacific Ocean. The first set of numbers (1, 2 or 3 digits) denotes the Marsden Square number. The second number is the quadrant (5° block of lat. and long.) within the Marsden Square. See Figure 4.1 for location of stations. Solid line is absolute temperature. Shaded areas are anomalies of temperatures. The mean upon which anomalies were computed is the 20-year period 1948-67.

MSQ 9-1

YEAR

YEAR	VALUE	ANOMALY	OBS
1948	26.6	.1	317
1949	26.3	-.2	380
1950	26.1	-.5	454
1951	27.0	.5	413
1952	26.5	.0	477
1953	27.0	.5	350
1954	25.8	-.7	402
1955	25.7	-.8	331
1956	INSUF DATA		
1957	27.2	.7	352
1958	27.3	.8	432
1959	26.8	.3	734
1960	26.6	.0	890
1961	26.4	-.1	1257
1962	26.2	-.4	1225
1963	26.5	.0	919
1964	26.3	-.3	963
1965	26.8	.3	854
1966	26.7	.1	748
1967	26.1	-.5	717
1968	26.3	-.2	755
1969	27.2	.7	722
1970	26.2	-.3	899
1971	26.2	-.4	528
1972	27.6	1.1	243
1973	26.7	.2	224
1974	25.9	-.6	230



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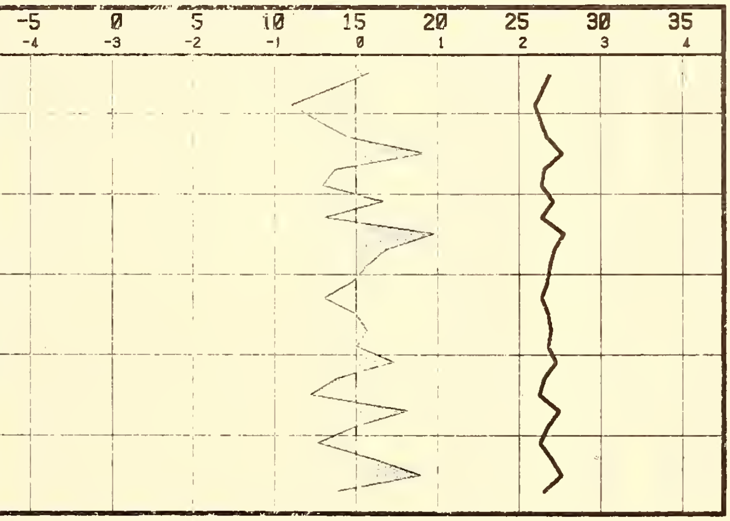
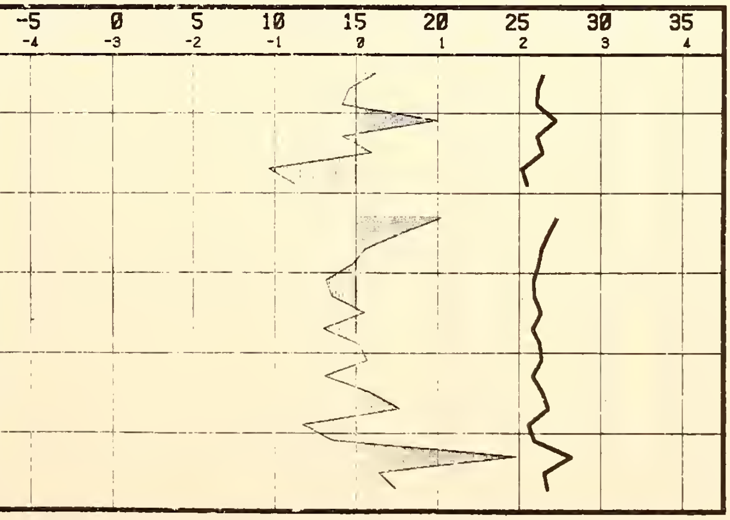
QTR	VALUE	ANOMALY	OBS
194801	26.9	.2	61
194901	26.4	-.3	35
195001	26.0	-.8	37
195101	26.3	-.5	90
195201	26.6	-.1	123
195301	27.6	.8	111
195401	26.5	-.3	102
195501	26.3	-.4	103
195601	27.1	.3	56
195701	26.4	-.4	73
195801	27.7	1.0	97
195901	27.1	.4	221
196001	26.9	.1	203
196101	26.7	-.0	315
196201	26.4	-.4	331
196301	26.7	-.0	211
196401	26.9	.1	231
196501	26.8	.0	229
196601	27.2	.5	154
196701	26.5	-.2	229
196801	26.2	-.6	219
196901	27.4	.6	217
197001	26.7	-.0	256
197101	26.3	-.5	244
197201	26.9	.2	65
197301	27.5	.8	59
197401	26.5	-.2	77



JULAUGSEP

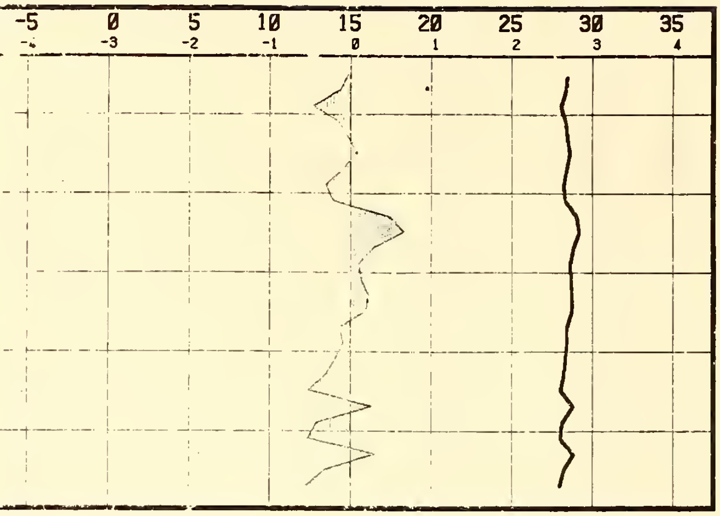
QTR	VALUE	ANOMALY	OBS
194803	26.5	.3	38
194903	26.1	-.1	111
195003	26.0	-.2	125
195103	27.2	1.0	108
195203	26.0	-.2	138
195303	26.4	.2	72
195403	25.1	-1.1	69
195503	25.5	-.8	69
195603	INSUF DATA		
195703	27.3	1.1	76
195803	26.8	.6	102
195903	26.3	.1	192
196003	26.2	-.0	221
196103	25.8	-.4	295
196203	25.9	-.3	290
196303	26.3	.1	203
196403	25.8	-.4	226
196503	26.3	.0	130
196603	26.3	.1	190
196703	25.8	-.4	152
196803	26.4	.2	175
196903	26.7	.5	159
197003	25.5	-.7	199
197103	25.9	-.3	98
197203	28.2	2.0	67
197303	26.5	.3	47
197403	26.7	.5	54



MSQ 46-1

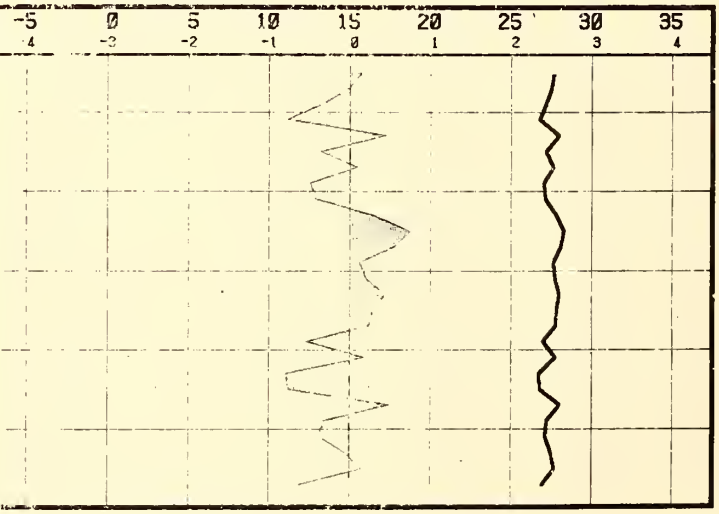
YEAR

YEAR	VALUE	ANOMALY	CBS
1948	28.5	-.0	336
1949	28.4	-.1	1311
1950	28.0	-.5	1750
1951	28.4	-.1	1875
1952	28.5	-.0	2421
1953	28.6	.1	2554
1954	28.4	-.1	2462
1955	28.2	-.3	2583
1956	28.3	-.2	2825
1957	29.0	.5	3255
1958	29.2	.7	3235
1959	28.8	.3	3631
1960	28.6	.1	4251
1961	28.6	.1	4146
1962	28.7	.2	3679
1963	28.7	.2	3433
1964	28.4	-.1	3750
1965	28.4	-.1	3802
1966	28.3	-.2	3837
1967	28.2	-.3	4202
1968	28.0	-.5	4073
1969	28.8	.3	4118
1970	28.1	-.4	3846
1971	28.0	-.5	2762
1972	28.8	.3	2066
1973	28.2	-.3	1532
1974	28.0	-.5	1538



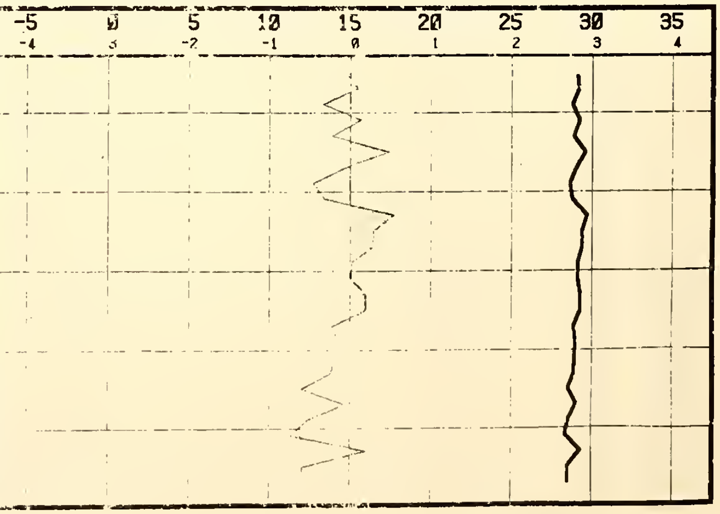
JANFEBMAR

QTR	VALUE	ANOMALY	CBS
194801	27.7	.2	66
194901	27.5	-.0	306
195001	27.2	-.3	401
195101	26.7	-.8	412
195201	27.9	.4	437
195301	27.1	-.4	637
195401	27.6	.1	539
195501	27.0	-.5	588
195601	27.1	-.4	624
195701	27.8	.3	769
195801	28.3	.8	710
195901	28.1	.5	846
196001	27.6	.1	1015
196101	27.7	.2	1027
196201	27.9	.4	360
196301	27.8	.3	885
196401	27.7	.2	807
196501	27.0	-.5	739
196601	27.7	.2	971
196701	26.7	-.8	880
196801	26.7	-.8	1013
196901	28.0	.5	651
197001	27.2	-.3	769
197101	27.1	-.4	870
197201	27.4	-.1	455
197301	27.7	.1	387
197401	26.9	-.6	427



JULAUGSEP

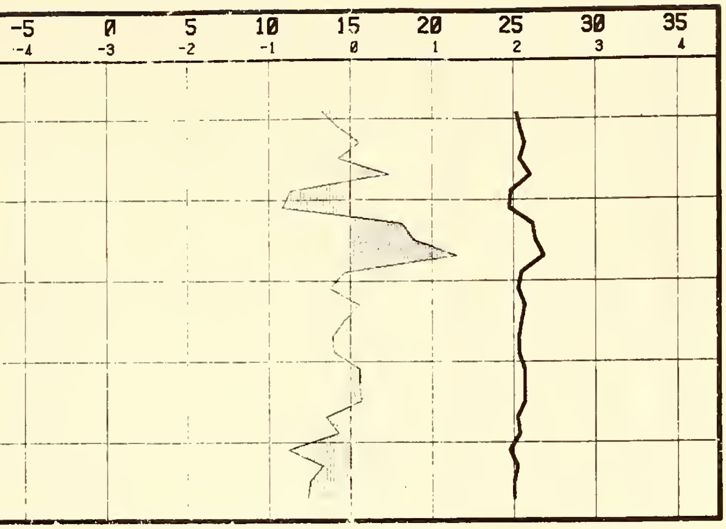
QTR	VALUE	ANOMALY	CBS
194803	29.0	-.1	37
194903	29.2	.1	235
195003	28.8	-.3	522
195103	29.2	.1	470
195203	28.9	-.2	637
195303	29.6	.5	656
195403	29.0	-.1	649
195503	28.6	-.5	705
195603	28.8	-.3	759
195703	29.6	.5	834
195803	29.4	.3	855
195903	29.4	.3	974
196003	29.1	.0	1072
196103	29.1	.0	1032
196203	29.3	.2	910
196303	29.3	.2	810
196403	28.9	-.2	1003
196503	28.9	-.1	1007
196603	28.9	-.2	1045
196703	28.8	-.2	1234
196803	28.5	-.6	[illegible]
196903	29.0	-.1	1129
197003	28.6	-.5	1049
197103	28.4	-.7	632
197203	29.3	.2	554
197303	28.5	-.6	335
197403	28.5	-.6	4.3



MSQ 48-4

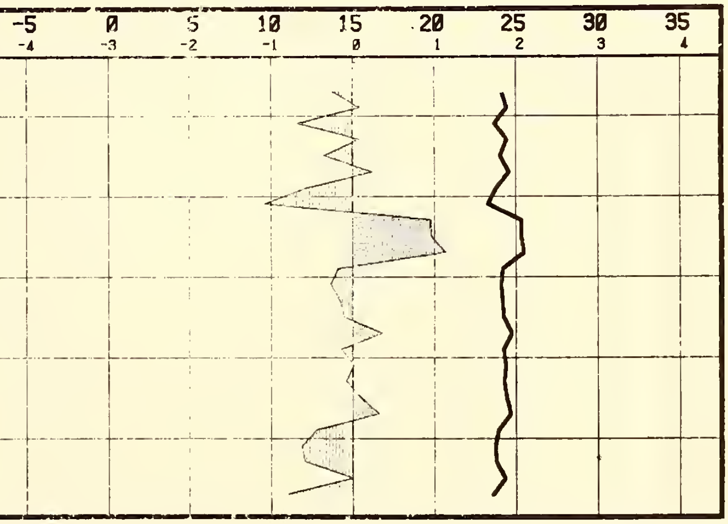
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	INSUF DATA		
1950	25.1	-.4	201
1951	25.4	-.2	247
1952	25.6	.1	334
1953	25.4	-.1	334
1954	28.0	.5	308
1955	24.8	-.7	292
1956	24.7	-.8	339
1957	26.2	.6	523
1958	26.3	.8	531
1959	26.8	1.3	537
1960	25.4	-.1	530
1961	25.3	-.3	556
1962	25.6	.1	641
1963	25.4	-.1	531
1964	25.3	-.2	535
1965	25.3	-.2	639
1966	25.6	.1	937
1967	25.6	.1	1422
1968	25.6	.1	1522
1969	25.2	-.3	1432
1970	25.4	-.1	1139
1971	24.8	-.8	759
1972	25.2	-.3	636
1973	25.0	-.5	609
1974	25.0	-.5	520



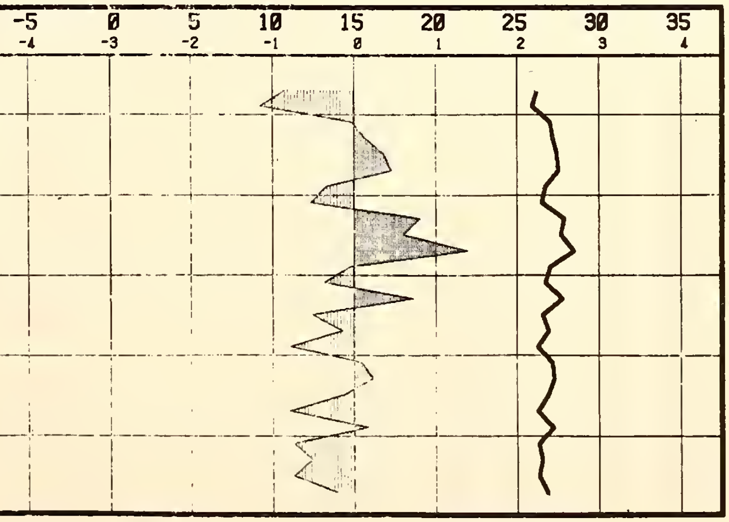
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	24.1	-.2	58
195001	24.4	.1	37
195101	23.7	-.7	59
195201	24.4	.1	64
195301	24.0	-.3	122
195401	24.6	.2	57
195501	23.8	-.6	59
195601	23.2	-1.1	[illegible]
195701	25.3	1.0	107
195801	25.3	1.0	171
195901	25.5	1.1	111
196001	24.1	-.2	99
196101	24.1	-.3	130
196201	24.2	-.2	179
196301	24.2	-.1	153
196401	24.7	.4	[illegible]
196501	24.2	-.1	[illegible]
196601	24.3	.0	228
196701	24.2	-.1	421
196801	24.4	.1	497
196901	24.7	.3	321
197001	23.9	-.4	356
197101	23.7	-.6	253
197201	23.7	-.6	239
197301	24.3	-.0	199
197401	23.5	-.8	2?2



JULAUGSEP

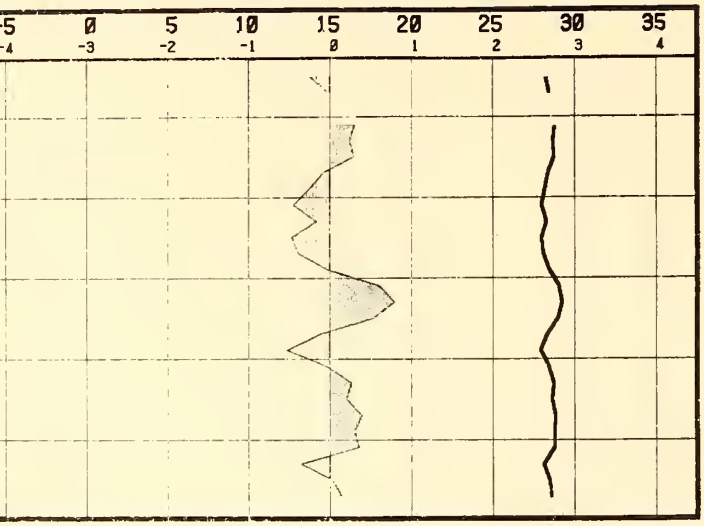
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	26.2	-.8	48
195003	25.9	-1.2	41
195103	27.0	-.0	59
195203	27.2	.1	90
195303	27.4	.4	123
195403	27.5	.4	88
195503	26.7	-.3	77
195603	26.5	-.5	119
195703	27.8	.8	136
195803	27.6	.6	115
195903	28.4	1.4	234
196003	27.0	-.0	153
196103	26.7	-.4	122
198203	27.8	.7	133
198303	26.5	-.5	111
196403	26.9	-.1	126
196503	26.3	-.8	[illegible]
196603	27.1	.1	[illegible]
196703	27.3	.2	[illegible]
196803	26.9	-.1	278
196903	26.3	-.8	396
197003	27.2	.2	[illegible]
197103	26.3	-.7	[illegible]
197203	26.5	-.5	137
197303	26.3	-.7	106
197403	26.8	-.2	123



MSQ 58-2

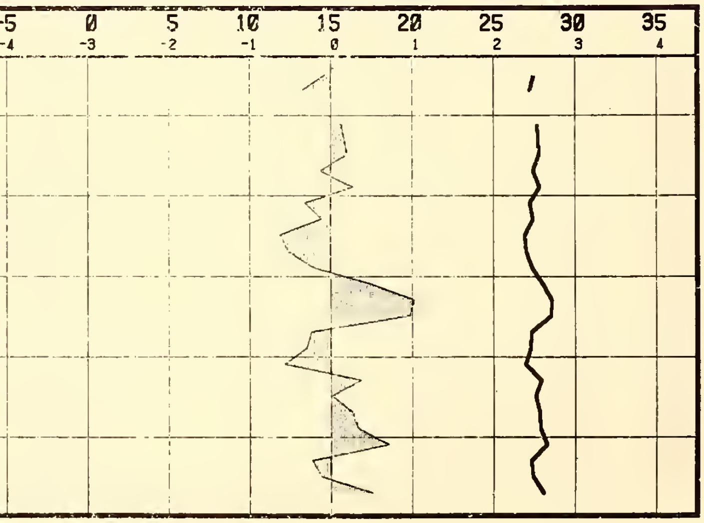
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	28.2	-.2	169
1949	28.4	-.Ø	255
195Ø	INSUF DATA		
1951	28.7	.3	2Ø8
1952	28.7	.2	226
1953	28.7	.3	33Ø
1954	28.3	-.1	238
1955	28.2	-.3	4Ø6
1956	28.Ø	-.5	524
1957	28.3	-.2	839
1958	28.Ø	-.5	735
1959	28.Ø	-.4	1226
196Ø	28.4	-.Ø	1445
1961	29.Ø	.6	359
1962	29.2	.8	35Ø
1963	28.9	.5	4Ø4
1964	28.3	-.1	1833
1965	27.9	-.5	1722
1966	28.4	-.Ø	1836
1967	28.7	.3	634
1968	28.6	.2	8Ø3
1969	28.8	.4	678
197Ø	26.7	.3	432
1971	28.8	.4	638
1972	28.1	-.3	137Ø
1973	28.5	.Ø	1437
1974	28.6	.1	1346



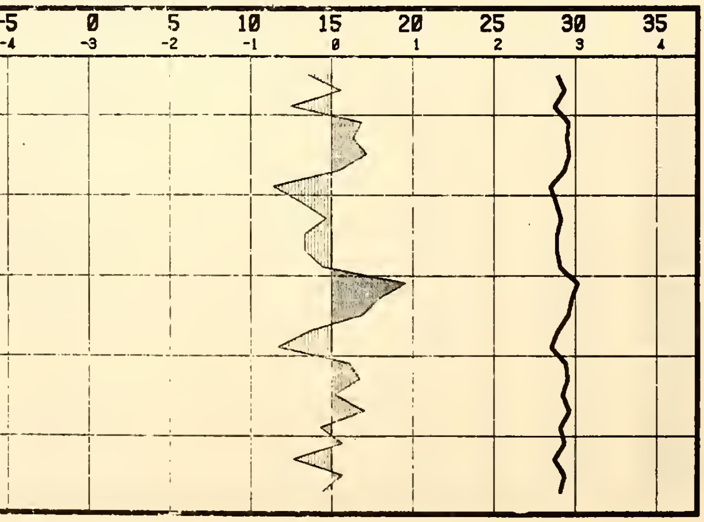
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
1948Ø1	27.5	-.1	42
1949Ø1	27.2	-.4	47
195ØØ1	INSUF DATA		
1951Ø1	27.7	.1	53
1952Ø1	27.7	.2	53
1953Ø1	27.7	.2	59
1954Ø1	27.4	-.1	33
1955Ø1	27.8	.3	33
1956Ø1	27.2	-.3	141
1957Ø1	27.4	-.1	132
1958Ø1	26.9	-.6	2Ø2
1959Ø1	27.Ø	-.5	272
196ØØ1	27.3	-.2	233
1961Ø1	28.Ø	.5	357
1962Ø1	28.6	1.Ø	31
1963Ø1	28.5	1.Ø	131
1964Ø1	27.3	-.2	397
1965Ø1	27.2	-.3	434
1966Ø1	27.Ø	-.6	478
1967Ø1	27.9	.4	138
1968Ø1	27.5	.Ø	223
1969Ø1	27.8	.3	2Ø3
197ØØ1	27.9	.3	151
1971Ø1	28.2	.7	133
1972Ø1	27.3	-.2	312
1973Ø1	27.4	-.1	352
1974Ø1	28.Ø	.5	3Ø8



JULAUGSEP

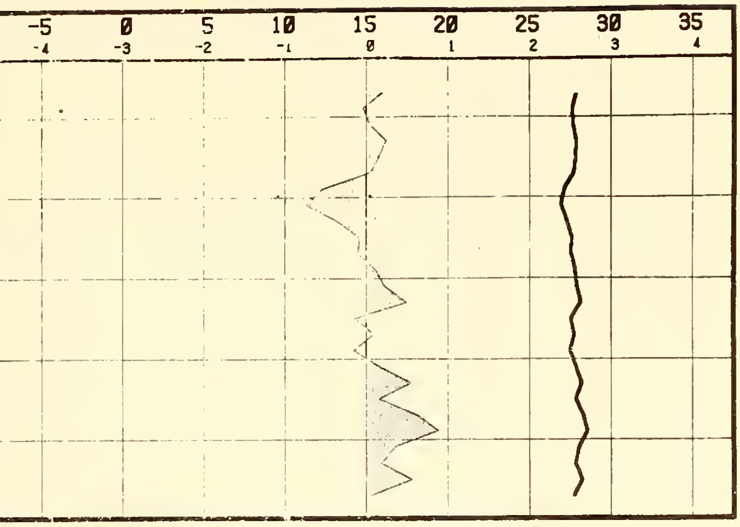
QTR	VALUE	ANOMALY	OBS
1948Ø3	28.9	-.3	4Ø
1949Ø3	29.3	.1	117
195ØØ3	28.7	-.5	5Ø
1951Ø3	29.5	.4	5Ø
1952Ø3	29.4	.3	59
1953Ø3	29.6	.4	35
1954Ø3	29.3	.1	53
1955Ø3	28.5	-.7	39
1956Ø3	28.8	-.4	132
1957Ø3	29.1	-.1	234
1958Ø3	28.8	-.3	154
1959Ø3	28.8	-.3	316
196ØØ3	29.1	-.1	372
1961Ø3	3Ø.1	.9	77
1962Ø3	29.8	.6	1Ø2
1963Ø3	29.6	.4	39
1964Ø3	28.9	-.3	438
1965Ø3	28.5	-.7	478
1966Ø3	29.4	.2	394
1967Ø3	29.5	.3	153
1968Ø3	29.2	.Ø	195
1969Ø3	29.6	.4	158
197ØØ3	29.Ø	-.1	72
1971Ø3	29.3	.1	1Ø7
1972Ø3	28.7	-.5	338
1973Ø3	29.3	.1	362
1974Ø3	29.1	-.1	357



MSQ 60-4

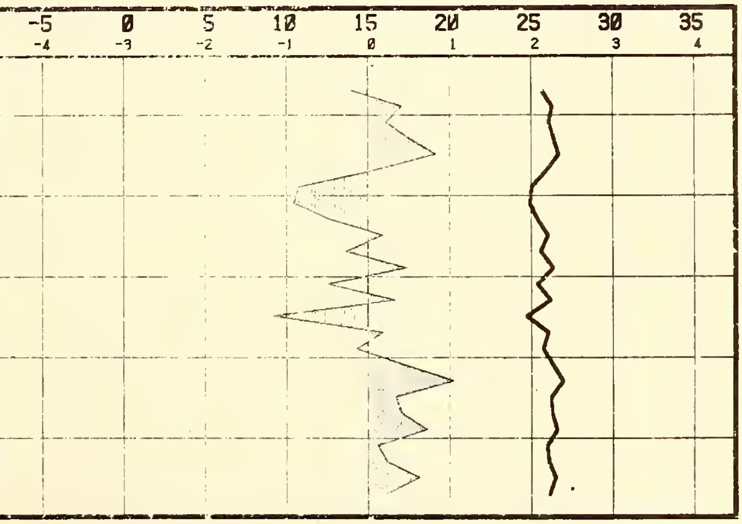
YEAR

YEAR	VALUE	ANOMALY	CBS
1948	INSUF DATA		
1949	27.8	.2	257
1950	27.6	-.0	175
1951	27.7	.0	233
1952	27.9	.2	230
1953	27.8	.2	751
1954	27.7	.1	959
1955	27.1	-.5	1362
1956	26.9	-.7	2205
1957	27.3	-.4	2872
1958	27.5	-.1	4123
1959	27.5	-.1	5431
1960	27.7	.1	6504
1961	27.8	.2	2390
1962	28.1	.5	157
1963	27.5	-.1	159
1964	27.7	.1	6374
1965	27.5	-.2	5975
1966	27.8	.2	6876
1967	28.2	.5	561
1968	27.8	.2	593
1969	28.2	.6	543
1970	28.5	.9	308
1971	28.0	.4	[illegible]
1972	27.8	.2	1053
1973	28.2	.6	834
1974	27.7	.1	929



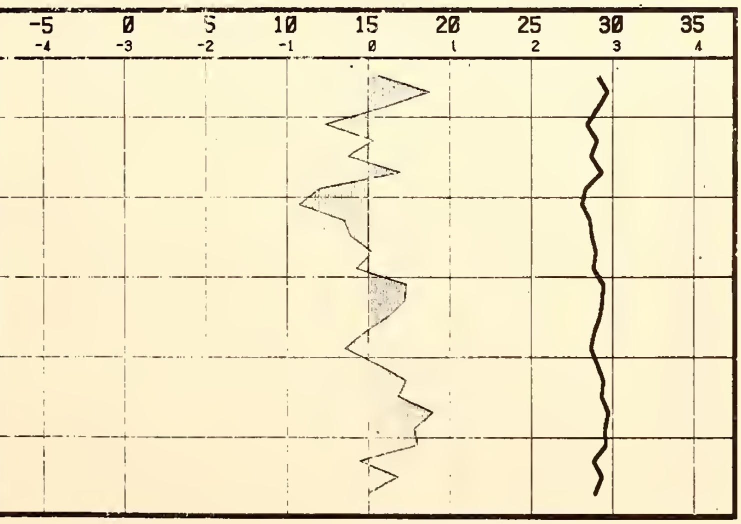
JANFEBMAR

QTR	VALUE	ANOMALY	CBS
194801	INSUF DATA		
194901	25.6	-.2	59
195001	26.3	.4	50
195101	26.1	.2	[illegible]
195201	26.3	.5	57
195301	26.7	.8	53
195401	25.9	.1	242
195501	25.0	-.8	302
195601	24.9	-.9	412
195701	25.4	-.5	723
195801	26.0	.2	757
195901	25.6	-.3	1353
196001	26.3	.5	[illegible]
196101	25.4	-.5	1214
196201	26.2	.3	42
196301	24.7	-1.2	32
196401	26.0	.2	1677
196501	25.7	-.1	1396
196601	26.3	.5	1734
196701	26.9	1.0	132
196801	26.2	.3	98
196901	26.3	.4	149
197001	26.6	.7	96
197101	26.0	.1	45
197201	26.1	.2	196
197301	26.5	.6	253
197401	26.1	.2	226



JULAUGSEP

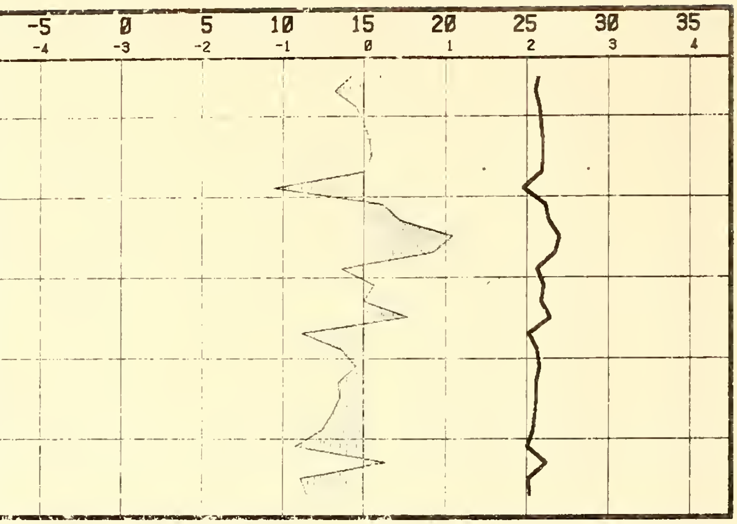
QTR	VALUE	ANOMALY	CBS
194803	29.0	.1	28
194903	29.7	.7	56
195003	29.1	.1	29
195103	28.4	-.5	24
195203	29.0	.1	52
195303	28.7	-.3	211
195403	29.3	.4	130
195503	28.3	-.6	229
195603	28.1	-.8	631
195703	28.6	-.3	713
195803	28.7	-.2	1120
195903	29.0	.0	1271
196003	28.8	-.1	1354
196103	29.4	.5	30
196203	29.4	.4	41
196303	29.2	.3	39
196403	28.9	-.1	1576
196503	28.6	-.3	1533
196603	29.0	.1	1726
196703	29.4	.5	[illegible]
196803	29.3	.4	134
196903	29.7	.8	143
197003	29.5	.6	105
197103	29.5	.6	96
197203	28.8	-.1	355
197303	29.3	.4	222
197403	28.9	-.0	255



MSQ 83-2

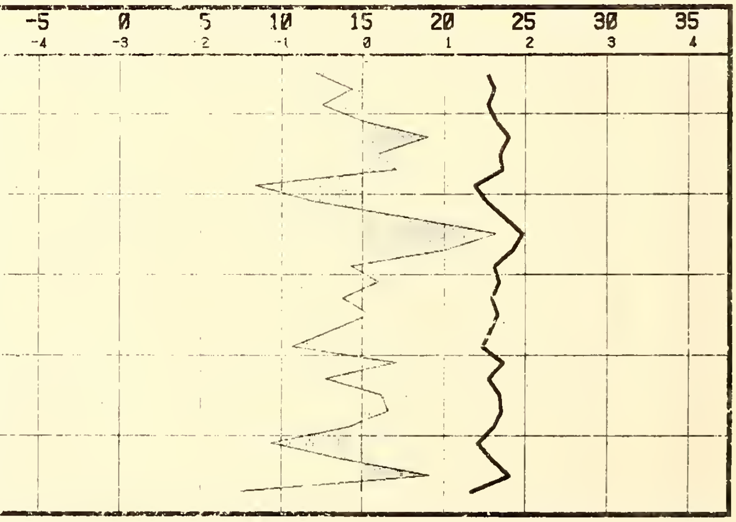
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	25.7	-.1	271
1949	25.5	-.4	937
1950	25.8	-.1	1334
1951	25.9	-.0	1372
1952	25.9	.1	1802
1953	26.0	.1	1770
1954	25.9	.0	1833
1955	24.7	-1.1	1955
1956	26.1	.2	24[illegible]
1957	26.3	.5	2595
1958	26.9	1.1	2853
1959	26.7	.9	3336
1960	25.6	-.3	3536
1961	26.0	.1	3254
1962	25.9	-.0	3333
1963	26.4	.5	2735
1964	25.1	-.8	3033
1965	25.6	-.3	2837
1966	25.8	-.1	25[illegible]
1967	25.6	-.3	25[illegible]
1968	25.6	-.3	2750
1969	25.5	-.4	2771
1970	25.3	-.5	25[illegible]
1971	25.0	-.8	19[illegible]7
1972	26.1	.3	1693
1973	25.1	-.8	1542
1974	25.2	-.7	1657



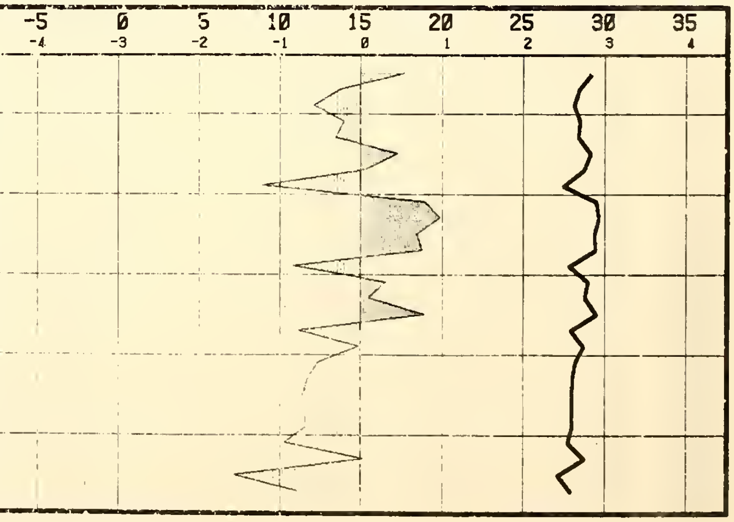
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	22.6	-.6	[illegible]
194901	23.0	-.1	2[illegible]
195001	22.7	-.5	297
195101	23.2	-.0	[illegible]
195201	24.0	.8	333
195301	23.4	.2	478
195401	23.6	.4	[illegible]
195501	21.8	-1.3	459
195601	22.5	-.6	5[illegible]
195701	23.7	.5	535
195801	24.8	1.6	539
195901	24.2	1.0	844
196001	23.0	-.1	8[illegible]
196101	23.4	.2	8[illegible]
196201	22.9	-.3	8[illegible]
196301	23.2	.1	693
196401	22.8	-.4	748
196501	22.3	-.9	613
196601	23.6	.4	749
196701	22.7	-.5	599
196801	23.4	.2	698
196901	23.5	.3	639
197001	23.0	-.2	550
197101	22.0	-1.1	5[illegible]
197201	22.9	-.3	350
197301	24.0	.8	344
197401	21.7	-1.5	4[illegible]



JULAUGSEP

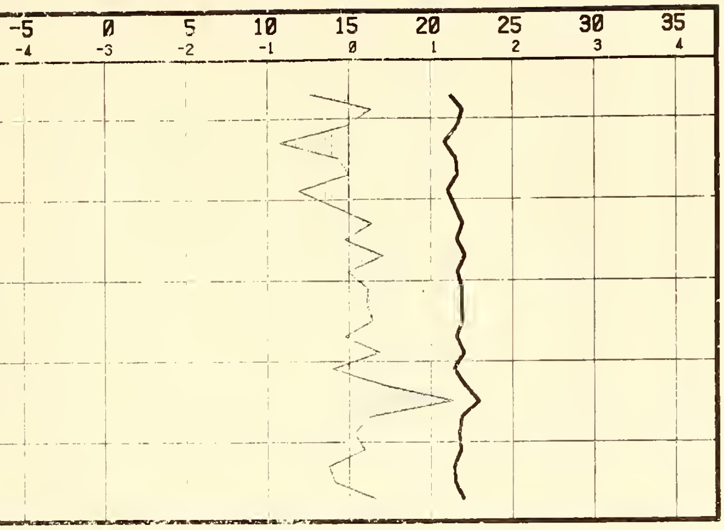
QTR	VALUE	ANOMALY	OBS
194803	29.2	.5	[illegible]58
194903	28.4	-.3	720
195003	28.1	-.6	3[illegible]
195103	28.5	-.2	32[illegible]
195203	28.3	-.3	520
195303	29.1	.5	427
195403	28.7	.0	480
195503	27.4	-1.2	5[illegible]
195603	29.4	.0	631
195703	29.6	1.0	693
195803	29.3	.7	746
195903	29.4	.7	83[illegible]
196003	27.8	-.8	85[illegible]
196103	29.0	.3	86[illegible]
196203	28.8	.1	790
196303	29.4	.8	636
196403	27.9	-.8	750
196503	28.6	-.0	7[illegible]
196603	28.1	-.5	[illegible]
196703	28.0	-.7	735
196803	27.9	-.7	612
196903	28.0	-.7	7[illegible]
197003	28.0	-.7	6[illegible]
197103	27.7	-1.0	4[illegible]
197203	28.7	.0	435
197303	27.1	-1.6	390
197403	27.9	-.8	4[illegible]



MSQ 87-3

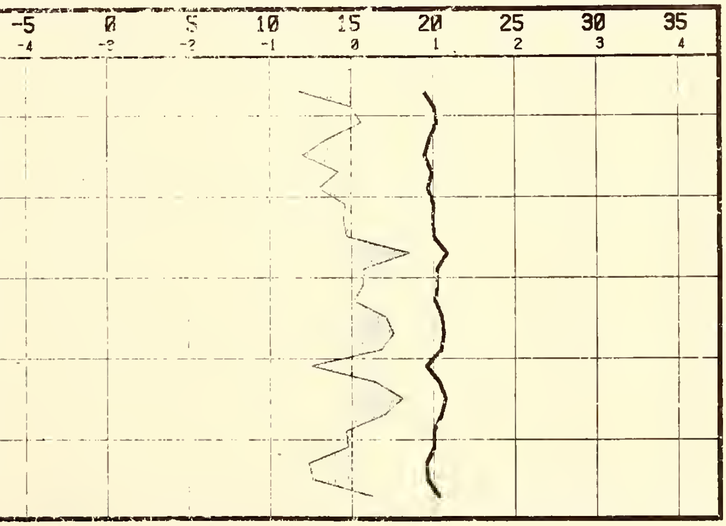
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	21.1	-.5	734
1950	21.9	.3	832
1951	21.6	-.0	1131
1952	20.8	-.8	1152
1953	21.5	-.1	1526
1954	21.6	.0	1344
1955	21.0	-.6	1403
1956	21.5	-.2	1558
1957	21.9	.3	2033
1958	21.6	-.1	1839
1959	22.0	.4	1877
1960	21.6	-.0	2133
1961	21.9	.2	2231
1962	21.8	.2	2133
1963	21.9	.3	2037
1964	21.6	-.1	2116
1965	22.0	.4	2455
1966	21.4	-.2	2852
1967	22.0	.4	2658
1968	22.9	1.3	2876
1969	21.9	.2	3033
1970	21.7	.1	3147
1971	21.8	.2	2236
1972	21.4	-.2	1896
1973	21.4	-.2	1507
1974	21.9	.3	1277



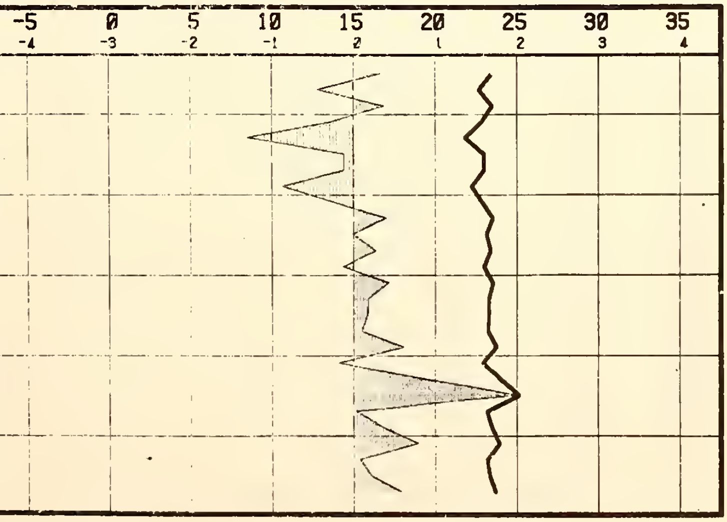
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	19.4	-.7	208
195001	20.1	-.0	153
195101	20.2	.1	335
195201	19.8	-.3	234
195301	19.5	-.6	398
195401	19.9	-.2	382
195501	19.7	-.4	338
195601	20.0	-.1	334
195701	20.0	-.1	459
195801	20.0	-.1	508
195901	20.8	.7	415
196001	20.2	.2	536
196101	20.2	.1	637
196201	20.1	.0	517
196301	20.5	.4	516
196401	20.6	.5	537
196501	20.4	.4	630
196601	19.6	-.5	777
196701	20.4	.3	745
196801	20.7	.6	830
196901	20.5	.4	771
197001	20.0	-.1	963
197101	20.0	-.1	628
197201	19.5	-.5	526
197301	19.6	-.5	525
197401	20.3	.2	351



JULAUGSEP

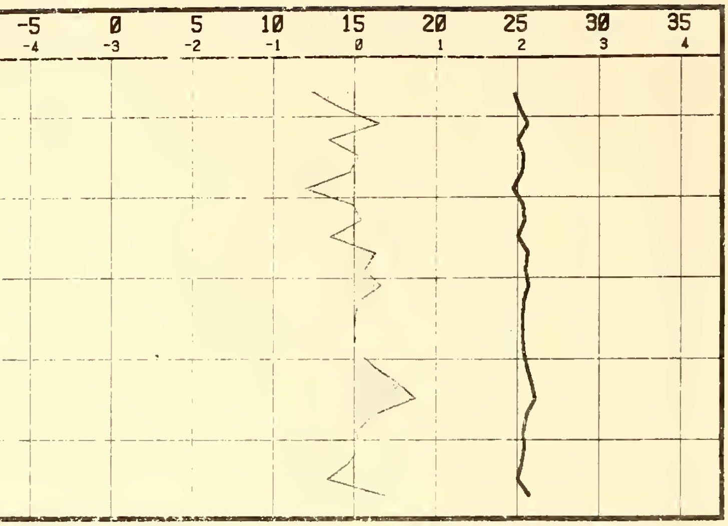
QTR	VALUE	ANOMALY	OBS
194803	23.4	.3	4
194903	22.7	-.4	143
195003	23.5	.4	219
195103	22.8	-.3	295
195203	21.8	-1.3	294
195303	23.0	-.1	330
195403	23.0	-.1	335
195503	22.2	-.9	319
195603	22.8	-.2	395
195703	23.5	.4	509
195803	23.1	-.0	475
195903	23.4	.3	492
196003	23.0	-.1	570
196103	23.5	.4	562
196203	23.3	.2	514
196303	23.3	.2	496
196403	23.2	.1	511
196503	23.7	.6	570
196603	22.9	-.2	538
196703	23.3	.9	673
196803	25.1	2.0	635
196903	23.1	.0	772
197003	23.5	.4	725
197103	23.9	.8	471
197203	23.2	.1	433
197303	23.3	.2	271
197403	23.7	.6	253



MSQ 89-1

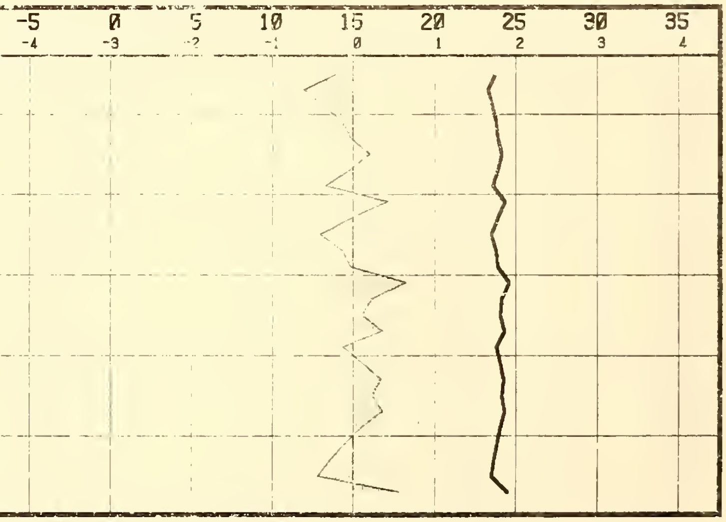
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	24.8	-.5	1039
1950	25.1	-.2	441
1951	25.6	.3	477
1952	25.0	-.3	657
1953	25.4	.1	765
1954	25.3	-.1	859
1955	24.7	-.6	931
1956	25.3	-.0	1010
1957	25.4	.1	1214
1958	25.0	-.3	1256
1959	25.6	.3	1409
1960	25.4	.1	1273
1961	25.6	.3	1595
1962	25.4	.0	1730
1963	25.3	.0	1656
1964	25.3	-.0	1849
1965	25.3	.0	2137
1966	25.6	.2	2444
1967	25.8	.5	2708
1968	26.1	.8	3035
1969	25.6	.3	2531
1970	25.3	.0	2472
1971	25.4	.1	1715
1972	25.2	-.1	1641
1973	25.0	-.3	1132
1974	25.7	.4	1055



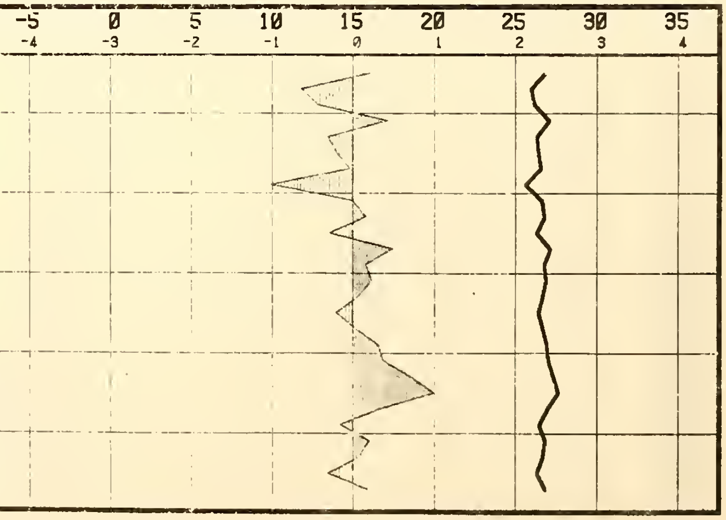
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	23.7	-.2	222
194901	23.3	-.6	278
195001	23.5	-.4	100
195101	23.7	-.1	115
195201	23.9'	-.0	170
195301	24.1	.2	223
195401	23.8	-.0	216
195501	23.5	-.3	215
195601	24.3	.4	249
195701	23.9	-.0	304
195801	23.5	-.4	312
195901	23.7	-.1	295
196001	23.8	-.0	324
196101	24.5	.7	433
196201	24.1	.2	409
196301	24.0	.1	336
196401	24.2	.4	434
196501	23.8	-.1	575
196601	24.0	.1	634
196701	24.2	.3	751
196801	24.1	.2	908
196901	24.2	.4	727
197001	24.0	.1	833
197101	23.8	-.1	523
197201	23.6	-.3	389
197301	23.4	-.4	354
197401	24.4	.6	357



JULAUGSEP

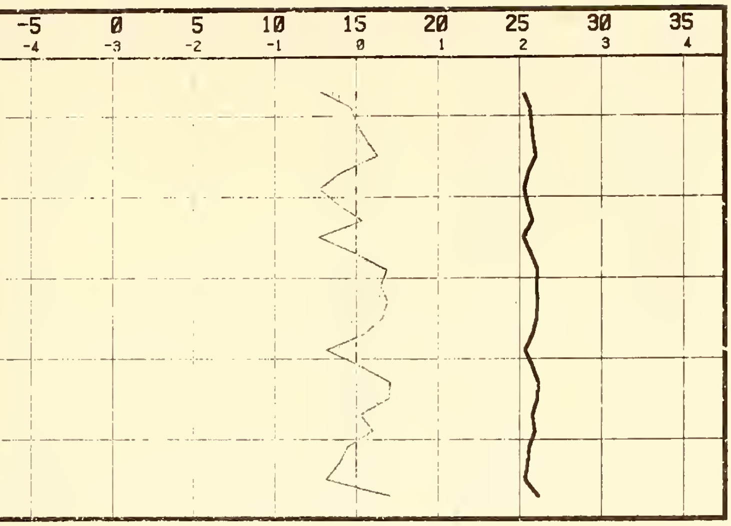
QTR	VALUE	ANOMALY	OBS
194803	26.9	.2	121
194903	26.0	-.6	382
195003	26.2	-.4	107
195103	27.0	.4	30
195203	26.3	-.3	174
195303	26.4	-.2	182
195403	26.6	-.0	184
195503	25.6	-1.0	247
195603	26.6	-.0	259
195703	26.8	.2	329
195803	26.3	-.3	335
195903	27.1	.5	369
196003	26.8	.2	320
196103	26.8	.2	429
196203	26.7	.1	421
196303	26.4	-.2	421
196403	26.6	.0	438
196503	26.9	.3	455
196603	27.0	.4	578
196703	27.3	.7	679
196803	27.6	1.0	662
196903	26.9	.3	625
197003	26.4	-.2	615
197103	26.8	2	414
197203	26.7	.1	473
197303	26.3	-.3	310
197403	26.8	.2	270



MSQ 90-1

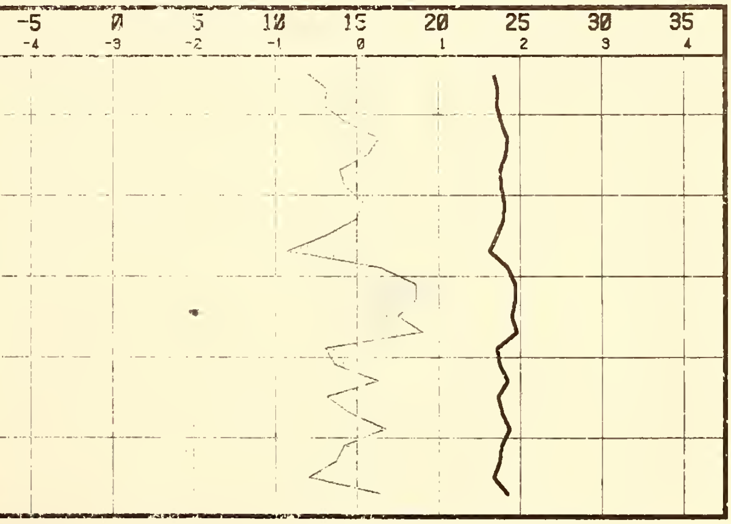
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	25.2	-.5	613
1950	25.6	-.1	239
1951	25.7	-.0	314
1952	25.8	.1	449
1953	25.9	.3	597
1954	25.5	-.2	531
1955	25.2	-.4	559
1956	25.5	-.2	658
1957	25.7	.1	730
1958	25.2	-.5	845
1959	25.7	-.0	772
1960	26.0	.4	823
1961	26.0	.3	930
1962	26.1	.4	857
1963	26.0	.3	934
1964	25.8	.1	1234
1965	25.3	-.4	1492
1966	25.7	.0	1830
1967	26.1	.4	1642
1968	26.1	.4	2134
1969	25.7	.1	1507
1970	25.9	.2	1434
1971	25.6	-.1	1001
1972	25.5	-.2	1130
1973	25.3	-.4	920
1974	26.1	.4	914



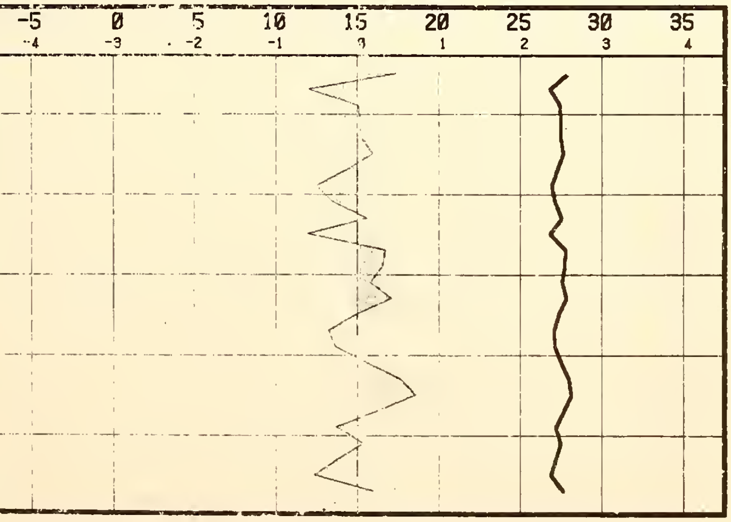
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	23.3	-.5	149
194901	23.6	-.4	172
195001	23.6	-.4	89
195101	23.8	-.1	93
195201	24.2	.3	125
195301	24.1	.1	138
195401	23.7	-.2	175
195501	23.8	-.1	136
195601	24.0	.1	155
195701	23.9	-.0	[illegible]
195801	23.6	-.4	[illegible]
195901	23.1	-.9	134
196001	24.2	.3	227
196101	24.7	.7	323
196201	24.7	.7	275
196301	24.4	.5	280
196401	24.7	.8	[illegible]
196501	23.6	-.4	409
196601	23.7	-.3	537
196701	24.2	.3	513
196801	23.6	-.4	[illegible]
196901	23.8	-.1	439
197001	24.3	.3	549
197101	23.8	-.2	320
197201	23.7	-.3	297
197301	23.4	-.6	235
197401	24.2	.3	350



JULAUGSEP

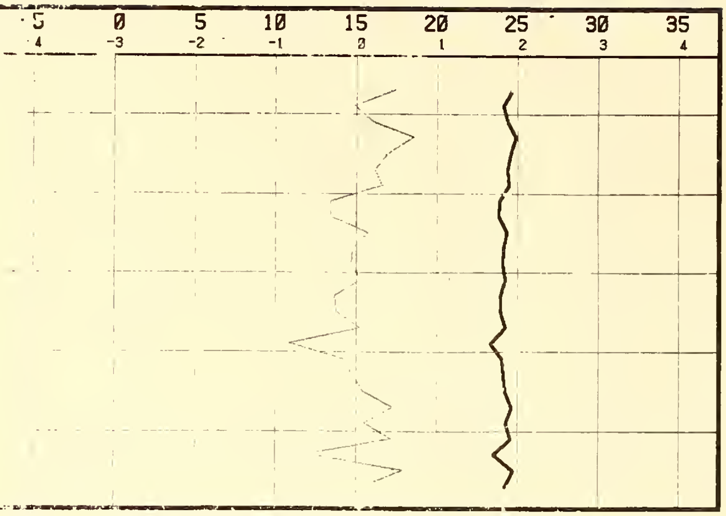
QTR	VALUE	ANOMALY	OBS
194803	27.9	.5	66
194903	26.8	-.6	226
195003	27.4	.0	53
195103	27.4	.0	73
195203	27.4	.1	107
195303	27.6	.2	127
195403	27.3	-.1	150
195503	26.9	-.5	85
195603	27.1	-.3	153
195703	27.5	.1	216
195803	26.8	-.6	133
195903	27.7	.3	177
196003	27.7	.3	125
196103	27.6	.2	190
196203	27.8	.4	152
196303	27.4	-.0	191
196403	27.0	-.4	258
196503	27.1	-.3	314
196603	27.5	.1	376
196703	27.9	.5	[illegible]
196803	28.1	.7	348
196903	27.3	.3	295
197003	27.1	-.3	287
197103	27.5	.1	275
197203	27.2	-.2	275
197303	26.9	-.5	166
197403	27.6	.2	156



MSQ 91-3

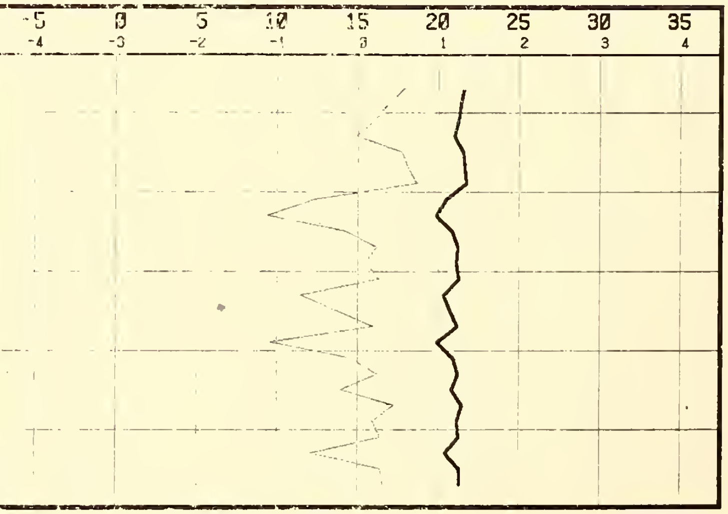
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	24.6	.5	359
1950	24.1	-.0	303
1951	24.3	.2	433
1952	24.9	.7	440
1953	24.5	.4	800
1954	24.4	.2	656
1955	24.5	.3	524
1956	23.8	-.3	537
1957	23.0	-.3	635
1958	24.3	.1	832
1959	24.1	-.0	753
1960	24.1	-.1	752
1961	24.2	.0	[illegible]
1962	23.9	-.3	761
1963	23.9	-.2	826
1964	24.2	.0	1322
1965	23.3	-.8	1550
1966	24.0	-.2	2231
1967	24.1	-.1	2233
1968	24.2	.1	2059
1969	24.6	.5	1819
1970	24.2	.1	1331
1971	24.6	.4	1096
1972	23.5	-.6	10.0
1973	24.7	.6	931
1974	24.2	.1	1000



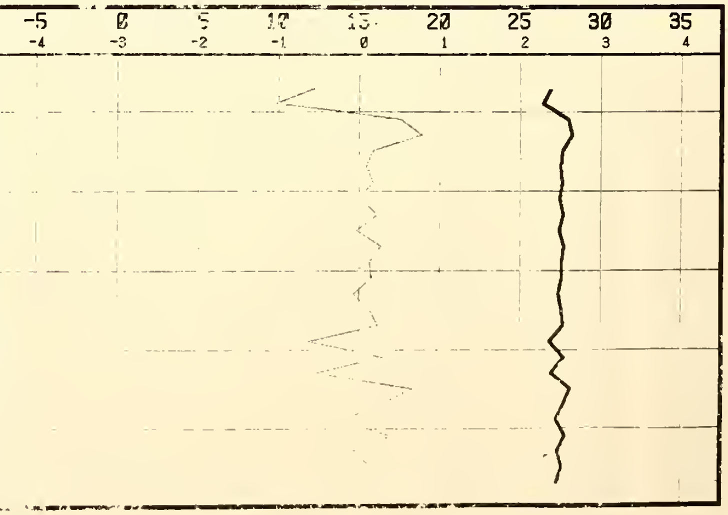
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	21.6	.6	99
195001	21.4	.4	124
195101	21.2	.2	128
195201	21.0	-.0	156
195301	21.5	.5	294
195401	21.6	.6	154
195501	21.7	.7	171
195601	20.4	-.5	157
195701	19.9	-1.1	145
195801	20.6	-.1	256
195901	21.2	.2	244
196001	21.1	.1	275
196101	21.2	.3	336
196201	20.3	-.7	269
196301	20.7	-.3	239
196401	21.2	.2	437
196501	19.9	-1.1	432
196601	20.9	-.1	765
196701	21.2	.2	730
196801	20.8	-.2	572
196901	21.4	.4	531
197001	21.2	.2	632
197101	21.3	.3	333
197201	20.4	-.6	3[illegible]
197301	21.3	.3	331
197401	21.3	.3	434



JULAUGSEP

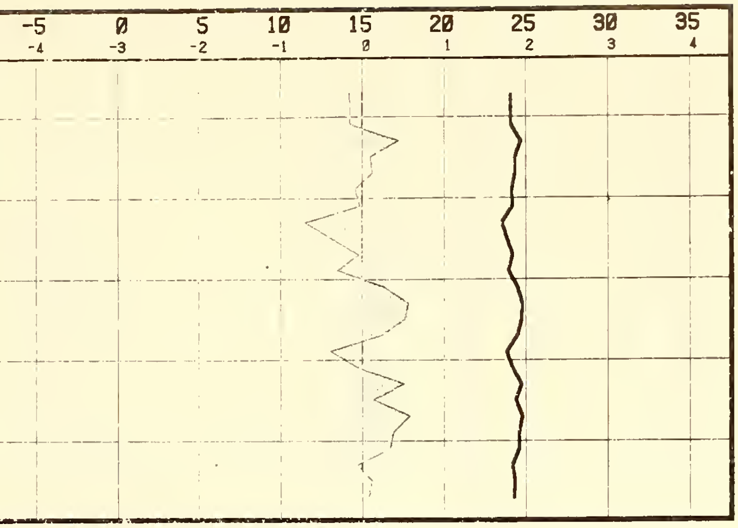
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	26.9	-.5	96
195003	26.4	-1.0	54
195103	27.9	.5	56
195203	28.2	.8	68
195303	27.6	.2	121
195403	27.5	.1	168
195503	27.6	.2	73
195603	27.4	.0	91
195703	27.7	.2	154
195803	27.4	-.0	172
195903	27.7	.3	131
196003	27.6	.1	123
196103	27.6	.2	116
196203	27.4	-.1	129
196303	27.6	.1	146
196403	27.7	.2	260
196503	26.8	-.6	[illegible]
196603	27.7	.3	[illegible]
196703	26.9	-.5	394
196803	28.1	.7	[illegible]
196903	27.7	.3	331
197003	27.2	-.2	[illegible]
197103	27.8	.4	192
197203	27.3	-.1	[illegible]
197303	27.6	.2	141
197403	27.3	-.1	154



MSQ 95-3

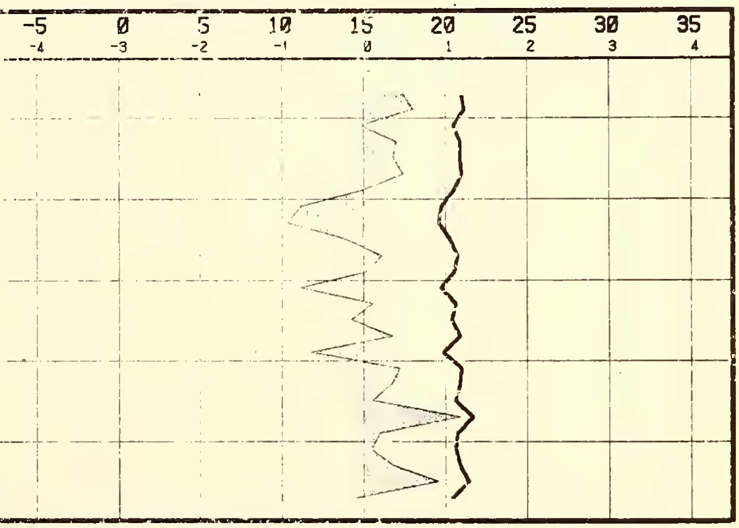
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	24.0	-.2	648
1950	24.0	-.1	731
1951	24.0	-.1	745
1952	24.6	.4	938
1953	24.3	.1	1616
1954	24.3	.1	2039
1955	24.1	-.1	3031
1956	24.2	-.0	4402
1957	23.5	-.7	5479
1958	23.8	-.4	5930
1959	24.1	-.0	7753
1960	23.9	-.3	8907
1961	24.5	.3	3973
1962	24.8	.6	1234
1963	24.7	.5	1257
1964	24.4	.2	6837
1965	23.8	-.4	7279
1966	24.1	-.1	7959
1967	24.7	.5	2273
1968	24.3	.1	1949
1969	24.8	.6	1532
1970	24.6	.4	1330
1971	24.5	.3	1232
1972	24.1	-.1	2835
1973	24.3	.1	2457
1974	24.3	.1	2039



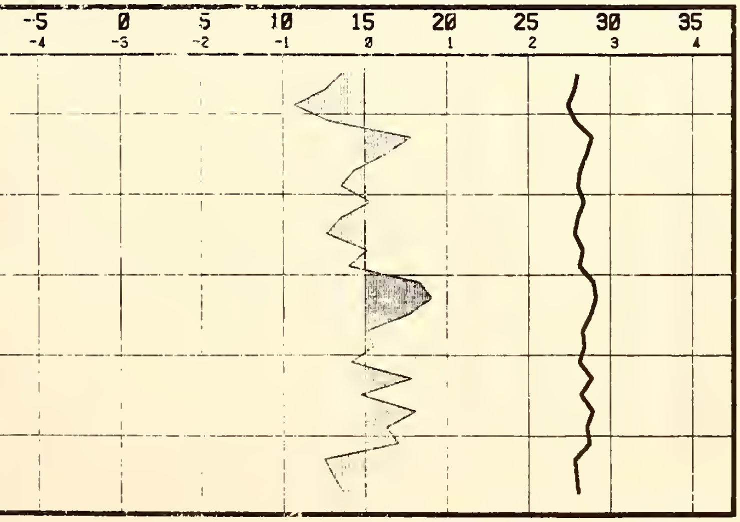
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	21.0	.5	114
195001	21.1	.6	217
195101	20.4	-.0	175
195201	20.9	.4	252
195301	20.8	.4	313
195401	21.0	.5	544
195501	20.5	-.0	668
195601	19.7	-.8	875
195701	19.6	-.9	1237
195801	20.3	-.2	1111
195901	20.7	.2	1822
196001	20.5	.0	22[illegible]
196101	19.7	-.8	1651
196201	20.6	.1	356
196301	20.3	-.2	234
196401	20.8	.4	1657
196501	19.8	-.[illegible]	14[illegible]9
196601	20.9	.4	17[illegible]
196701	20.8	.3	530
196801	20.6	.1	420
196901	21.7	1.2	303
197001	20.7	.2	271
197101	20.6	.1	170
197201	20.8	.3	474
197301	21.4	.9	456
197401	20.4	-.1	426



JULAUGSEP

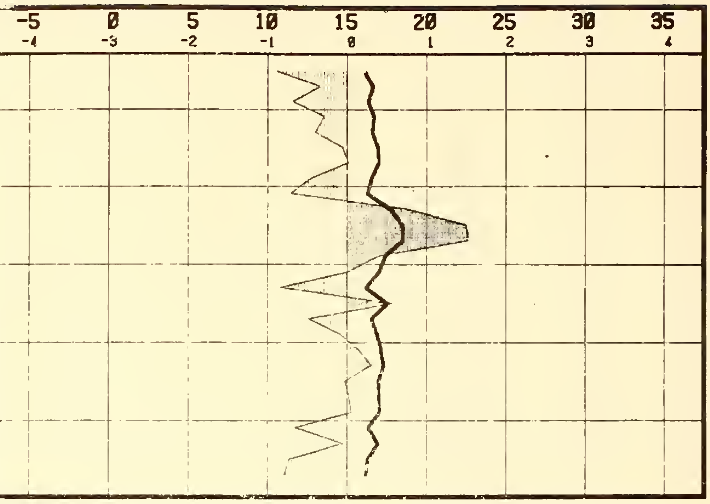
QTR	VALUE	ANOMALY	OBS
194803	28.0	-.3	57
194903	27.8	-.5	183
195003	27.4	-.9	1[illegible]
195103	27.9	-.4	133
195203	28.8	.6	228
195303	28.6	.3	399
195403	28.2	-.1	596
195503	28.0	-.3	630
195603	28.3	.1	1356
195703	28.0	-.3	1462
195803	27.8	-.5	1708
195903	28.3	.0	2124
196003	28.1	-.2	2348
196103	28.9	.7	375
196203	29.1	.8	370
196303	28.8	.5	412
198403	28.3	.0	2053
196503	28.4	.1	2034
196603	28.1	-.2	2318
196703	28.9	.6	691
196803	28.2	-.1	543
196903	28.9	.6	518
197003	28.5	.3	440
197103	28.7	.4	2[illegible]
197203	27.8	-.5	10[illegible]9
197303	27.9	-.4	8[illegible]
197403	28.0	-.3	985



MSQ 120-2

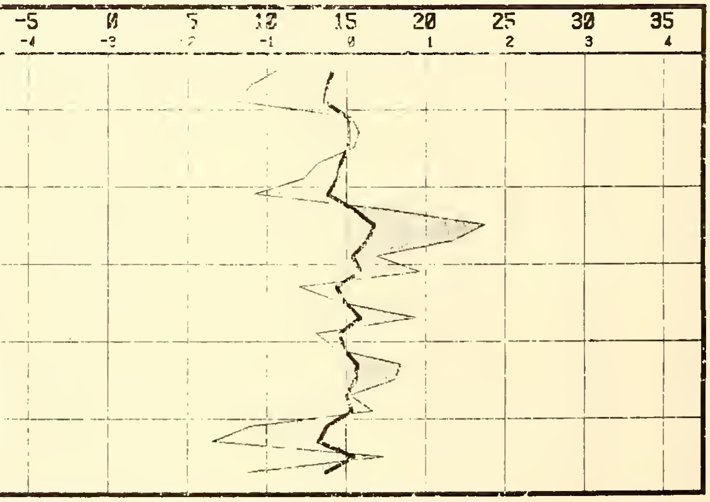
YEAR

YEAR	VALUE	ANOMALY	CBS
1948	16.1	-.9	3619
1949	16.6	-.3	4715
1950	16.3	-.7	4069
1951	16.7	-.3	2814
1952	16.6	-.4	2939
1953	16.9	-.1	3685
1954	17.0	.0	4528
1955	16.5	-.4	5307
1956	16.3	-.7	4678
1957	17.7	.8	4557
1958	18.5	1.5	3985
1959	18.5	1.5	4955
1960	17.3	.4	5871
1961	17.0	.0	5610
1962	16.1	-.8	5229
1963	17.5	.6	5470
1964	16.5	-.5	5254
1965	16.9	-.1	7657
1966	17.1	.1	7254
1967	17.3	.3	7002
1968	16.9	-.0	6714
1969	17.0	.0	5813
1970	17.0	.1	4925
1971	16.3	-.6	4705
1972	16.9	-.1	4118
1973	16.2	-.7	2361
1974	16.2	-.8	2665



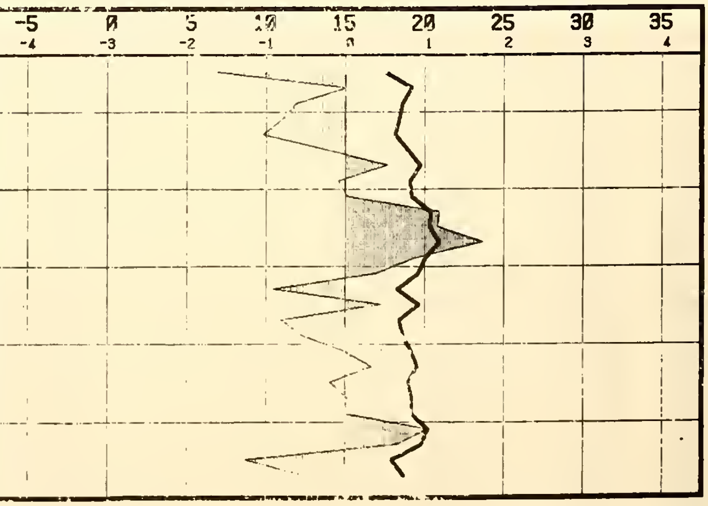
JANFEBMAR

QTR	VALUE	ANOMALY	CBS
194801	14.1	-.9	236
194901	13.7	-1.2	989
195001	13.6	-1.4	1668
195101	15.0	.0	978
195201	15.1	.2	532
195301	15.0	.1	923
195401	14.6	-.4	942
195501	14.4	-.5	1663
195601	13.8	-1.2	1338
195701	15.5	.5	1468
195801	16.7	1.7	871
195901	16.3	1.4	1279
196001	15.3	.4	1548
196101	15.9	.9	1433
196201	14.4	-.6	1760
196301	14.9	-.1	1391
196401	15.8	.9	1324
196501	14.6	-.4	1832
196601	14.8	-.1	1444
196701	15.6	.7	1515
196801	15.6	.6	1737
196901	15.0	.0	1816
197001	15.3	.3	1190
197101	13.8	-1.2	1325
197201	13.3	-1.7	1079
197301	15.4	.5	642
197401	13.7	-1.2	721



JULAUGSEP

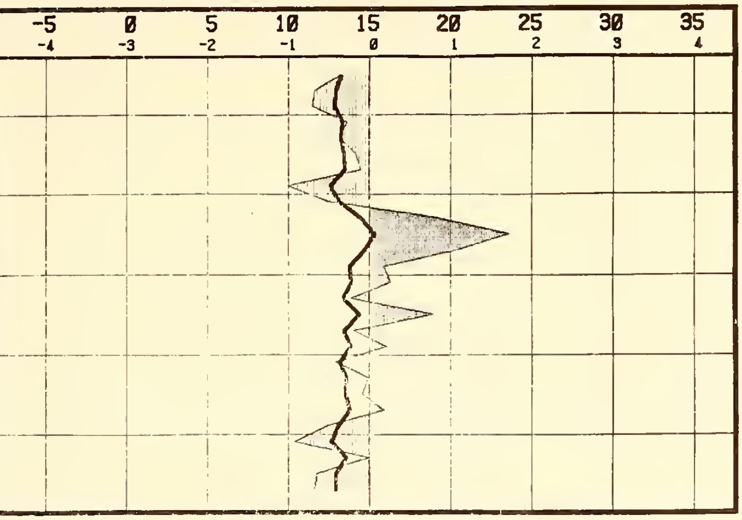
QTR	VALUE	ANOMALY	CBS
194803	17.5	-1.6	1401
194903	19.2	.0	1756
195003	18.5	-.6	793
195103	18.4	-.8	201
195203	18.1	-1.0	997
195303	18.9	-.2	777
195403	19.7	.5	1508
195503	19.1	-.1	1168
195603	19.2	.0	920
195703	20.3	1.2	958
195803	20.3	1.2	996
195903	20.9	1.7	1037
196003	20.0	.9	1300
196103	19.5	.4	1428
196203	18.2	-.9	1222
196303	19.6	.5	1252
196403	18.3	-.8	1340
196503	18.6	-.5	2178
196603	19.1	-.0	1775
196703	19.5	.3	1639
196803	19.0	-.2	1330
196903	19.2	.0	1728
197003	19.1	-.0	1919
197103	20.2	1.1	1277
197203	19.8	.7	807
197303	17.9	-1.3	695
197403	18.6	-.5	793



MSQ 121-3

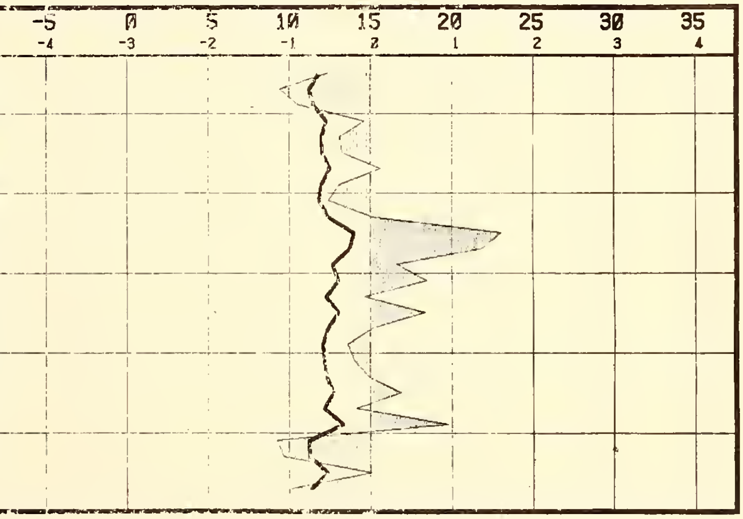
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	13.2	-.3	946
1949	12.9	-.7	1628
1950	12.9	-.7	1055
1951	13.3	-.3	1338
1952	13.2	-.4	935
1953	13.4	-.2	1052
1954	13.5	-.1	1262
1955	12.6	-1.0	1533
1956	13.1	-.5	1450
1957	14.4	.8	1398
1958	15.3	1.7	2049
1959	14.6	1.1	2555
1960	13.7	.2	2401
1961	13.8	.3	2425
1962	13.3	-.2	2043
1963	14.4	.8	1639
1964	13.4	-.2	1940
1965	13.3	.2	2449
1966	13.2	-.4	2837
1967	13.6	-.0	3344
1968	13.5	-.1	3372
1969	13.8	.2	2447
1970	13.0	-.5	4447
1971	12.6	-.9	2654
1972	13.6	-.0	1772
1973	12.9	-.7	1454
1974	12.9	-.7	2352



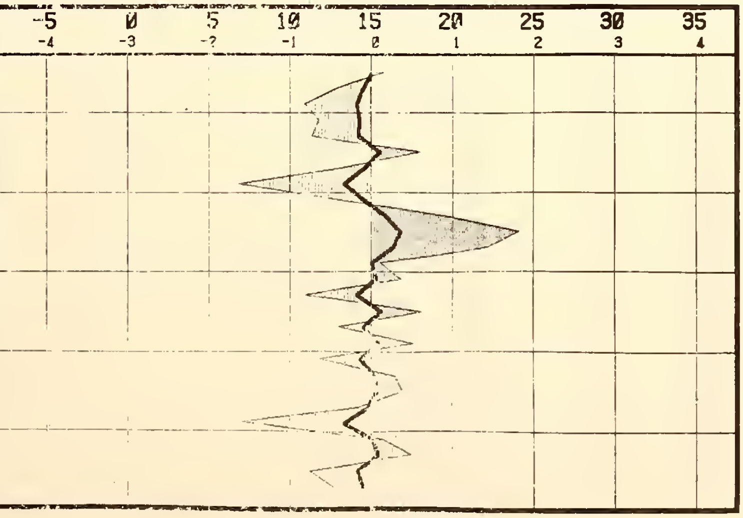
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	11.8	-.5	145
194901	11.2	-1.1	520
195001	11.4	-.9	276
195101	12.3	-.1	314
195201	12.0	-.4	230
195301	12.0	-.4	254
195401	12.5	.1	337
195501	12.0	-.4	416
195601	11.8	-.5	438
195701	12.3	.0	331
195801	13.9	1.6	233
195901	13.7	1.4	369
196001	12.7	.3	519
196101	13.0	.7	413
196201	12.3	-.1	434
196301	13.0	.7	427
196401	12.4	.0	[illegible]
196501	12.1	-.3	387
196601	12.1	-.2	579
196701	12.3	-.0	425
196801	12.7	.4	754
196901	12.2	-.2	531
197001	13.3	.9	974
197101	11.2	-1.2	941
197201	11.3	-1.1	379
197301	12.3	.0	250
197401	11.4	-1.0	731



JULAUGSEP

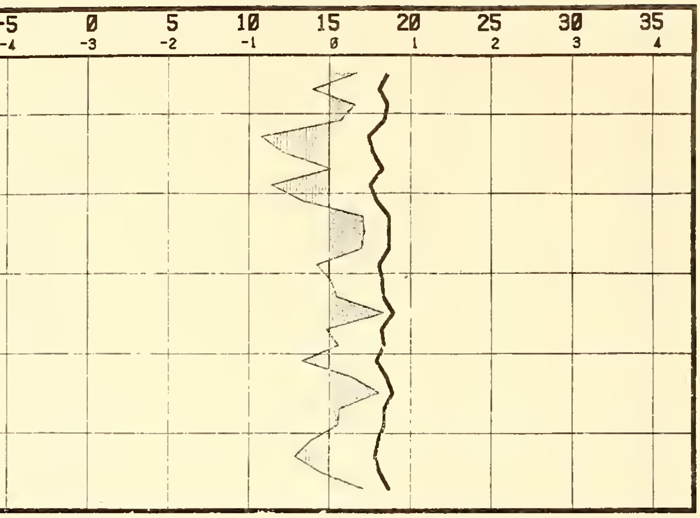
QTR	VALUE	ANOMALY	OBS
194803	15.1	.2	248
194903	14.5	-.4	514
195003	14.1	-.8	251
195103	14.3	-.6	217
195203	14.2	-.7	274
195303	15.5	.6	393
195403	14.5	-.4	321
195503	13.3	-1.6	342
195603	14.5	-.4	330
195703	15.9	1.0	355
195803	16.7	1.8	635
195903	16.4	1.4	812
196003	15.0	.1	713
196103	15.3	.4	636
196203	14.1	-.8	440
196303	15.5	.6	438
196403	14.5	-.4	614
196503	15.4	.5	[illegible]
196603	14.3	-.6	[illegible]
196703	15.2	[illegible]	[illegible]
196803	15.3	.4	[illegible]
196903	14.7	-.2	[illegible]
197003	13.3	-1.6	[illegible]
197103	15.1	.1	[illegible]
197203	15.4	.5	[illegible]
197303	14.2	-.8	[illegible]
197403	14.4	-.5	[illegible]



MSQ 122-1

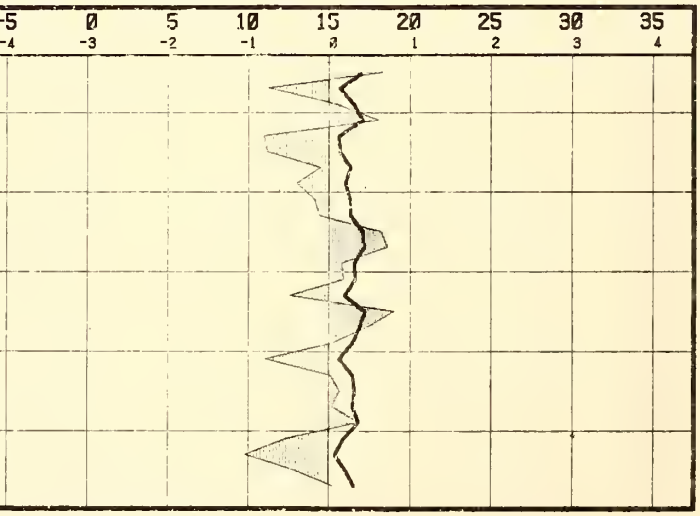
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	18.6	.3	440
1949	18.0	-.2	1130
1950	18.5	.3	1148
1951	18.4	.1	1778
1952	17.4	-.9	1547
1953	17.7	-.6	2130
1954	18.3	.0	1846
1955	17.5	-.7	1905
1956	17.9	-.3	2137
1957	18.7	.4	2515
1958	18.7	.4	2622
1959	18.6	.4	2735
1960	18.1	-.2	2938
1961	18.3	.0	3132
1962	18.3	.1	2838
1963	18.9	.7	2802
1964	18.2	-.0	2756
1965	18.3	.1	3094
1966	17.9	-.3	3507
1967	18.5	.3	3224
1968	18.8	.6	3661
1969	18.4	.1	3621
1970	18.3	.1	3547
1971	18.0	-.2	2839
1972	17.8	-.4	2292
1973	18.1	-.1	1929
1974	18.7	.4	1862



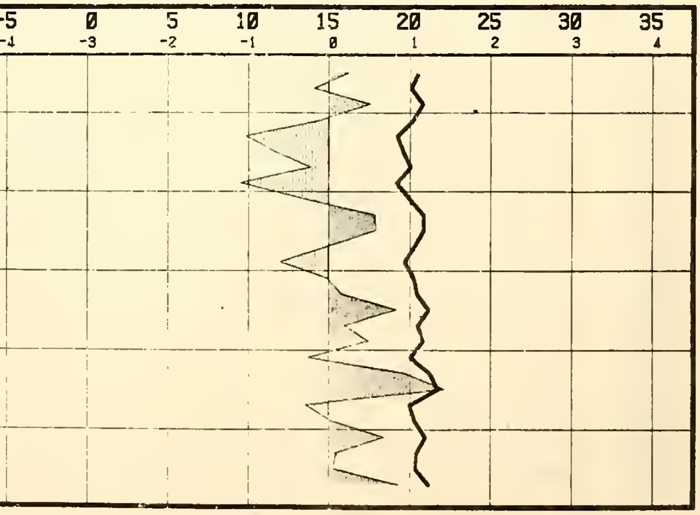
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	17.1	.7	109
194901	15.7	-.7	324
195001	16.5	.1	277
195101	17.0	.6	530
195201	15.6	-.8	470
195301	15.6	-.8	612
195401	16.3	-.1	530
195501	16.0	-.4	522
195601	16.2	-.2	600
195701	16.3	-.1	656
195801	17.1	.6	655
195901	17.1	.7	735
196001	16.6	.2	779
196101	16.6	.2	924
196201	15.9	-.5	803
196301	17.2	.8	715
196401	16.9	.5	721
196501	16.5	.0	836
196601	15.6	-.8	970
196701	16.4	.0	849
196801	16.5	.1	1038
196901	16.5	.0	920
197001	16.8	.4	973
197101	15.9	-.5	710
197201	15.4	-1.0	583
197301	16.0	-.4	551
197401	16.5	.1	381



JULAUGSEP

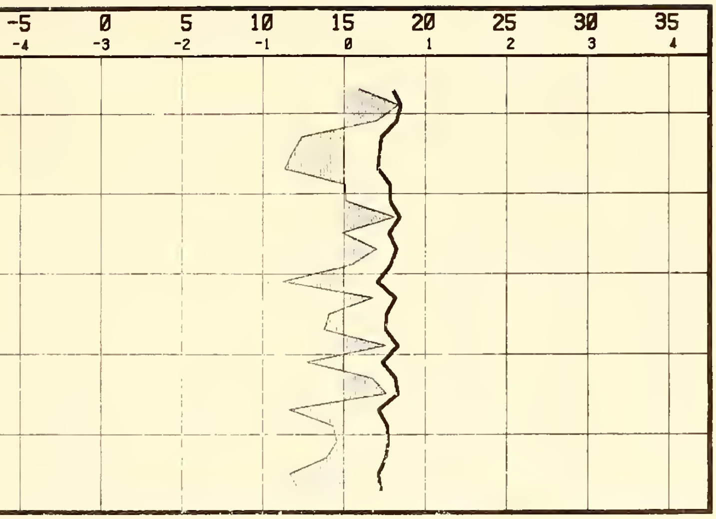
QTR	VALUE	ANOMALY	OBS
194803	20.5	.3	91
194903	20.1	-.2	210
195003	20.8	.5	258
195103	20.1	-.1	338
195203	19.2	-1.0	361
195303	19.6	-.7	507
195403	20.0	-.2	446
195503	19.1	-1.1	404
195603	19.9	-.3	519
195703	20.8	.6	579
195803	20.8	.6	658
195903	20.2	-.0	614
196003	19.6	-.6	738
196103	20.2	-.0	742
196203	20.4	.2	634
196303	21.1	.8	575
196403	20.4	.2	634
196503	20.7	.5	659
196603	20.0	-.3	773
196703	21.2	.9	713
196803	21.7	1.4	820
196903	20.0	-.3	847
197003	20.3	.0	332
187103	20.9	.7	614
197203	20.3	.1	595
197303	20.3	.1	470
197403	21.1	.9	581



MSQ 123-3

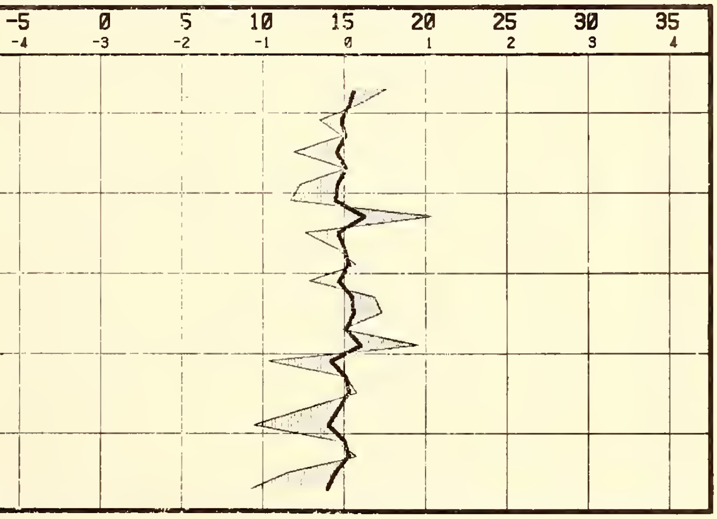
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	18.0	.2	478
1950	18.5	.7	384
1951	18.2	.4	436
1952	17.3	-.5	564
1953	17.1	-.6	581
1954	17.0	-.7	572
1955	17.8	.0	506
1956	17.8	.0	636
1957	18.4	.6	810
1958	17.8	-.0	690
1959	18.2	.4	735
1960	17.9	.1	962
1961	17.0	-.8	1073
1962	18.1	.4	1016
1963	17.6	-.2	921
1964	17.5	-.2	985
1965	18.3	.5	1237
1966	17.3	-.4	1453
1967	18.1	.3	1580
1968	18.3	.5	1563
1969	17.1	-.7	1403
1970	17.6	-.1	1346
1971	17.7	-.1	1243
1972	17.6	-.2	1400
1973	17.1	-.7	1286
1974	17.2	-.6	1324



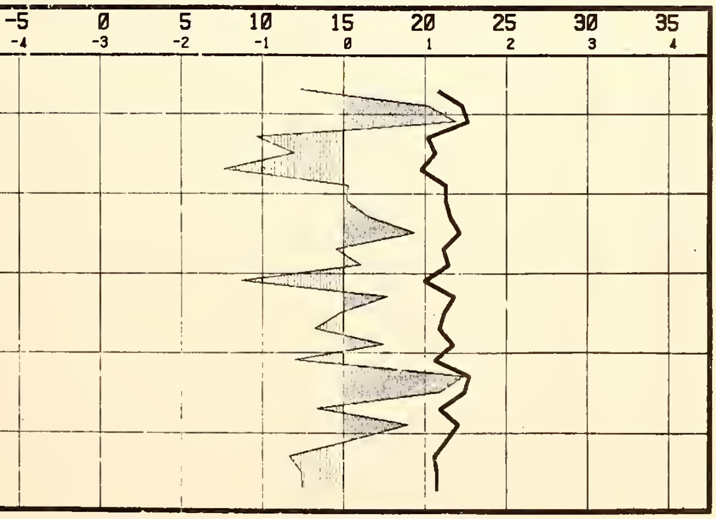
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	15.6	.5	128
195001	15.3	.2	93
195101	14.8	-.3	124
195201	15.1	-.0	130
195301	14.5	-.6	181
195401	15.1	.0	159
195501	14.6	-.5	112
195601	14.4	-.7	124
195701	16.2	1.1	203
195801	14.6	-.5	166
195901	15.0	-.1	187
196001	15.2	.1	257
196101	14.7	-.4	292
196201	15.5	.4	238
196301	15.6	.5	216
196401	15.1	-.0	224
196501	16.0	.9	229
196601	14.2	-.9	314
196701	15.1	.0	368
196801	15.2	.1	272
196901	14.6	-.5	294
197001	14.0	-1.1	230
197101	15.0	-.1	210
197201	15.2	.1	171
197301	14.4	-.7	253
197401	14.0	-1.1	259



JULAUGSEP

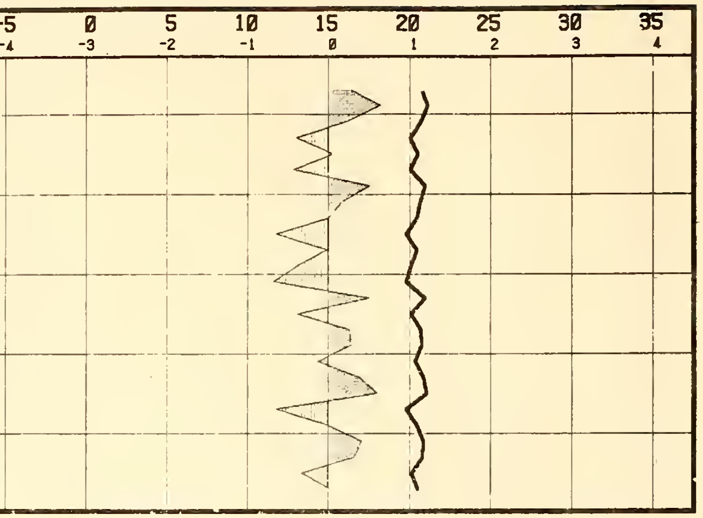
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	20.7	-.5	121
195003	22.3	1.0	91
195103	22.6	1.4	111
195203	20.2	-1.1	126
195303	20.6	-.6	114
195403	19.7	-1.5	140
195503	21.3	.0	139
195603	21.3	.0	163
195703	21.5	.3	184
195803	22.1	.9	147
195903	21.1	-.1	177
196003	21.4	.2	182
196103	20.0	-1.3	222
196203	21.8	.5	217
196303	21.2	-.0	184
196403	20.9	-.3	241
196503	21.7	.5	321
196603	20.6	-.6	402
196703	22.7	1.5	418
196803	22.4	1.2	427
196903	20.9	-.3	373
197003	22.0	.8	423
197103	21.3	.1	285
197203	20.6	-.7	431
197303	20.7	-.5	331
197403	20.7	-.5	417



MSQ 124-1

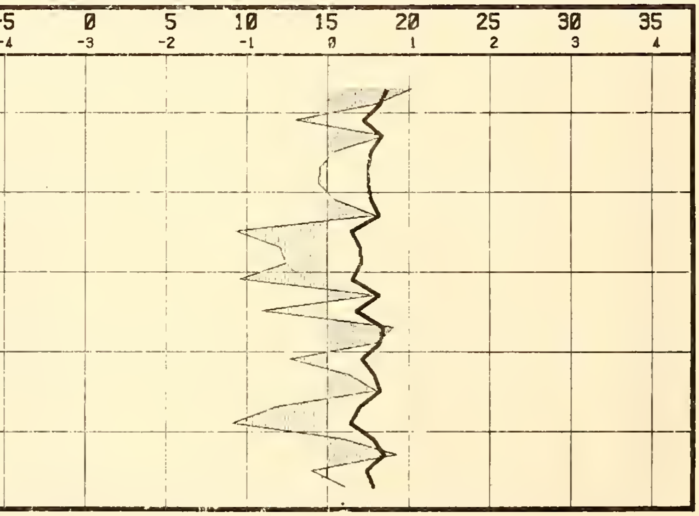
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA	.	
1949	20.7	.3	457
1950	21.0	.6	420
1951	20.6	.2	758
1952	20.0	-.4	806
1953	20.5	.1	1204
1954	20.0	-.4	838
1955	20.9	.5	813
1956	20.6	.2	979
1957	20.4	-.0	1067
1958	19.8	-.7	933
1959	20.4	-.0	1096
1960	20.0	-.4	1223
1961	19.7	-.7	1298
1962	20.9	.5	1784
1963	20.0	-.4	1000
1964	20.7	.3	1069
1965	20.7	.3	1382
1966	20.3	-.1	2220
1967	20.8	.4	2304
1968	21.0	.6	2291
1969	19.8	-.7	2187
1970	20.4	-.0	1708
1971	20.8	.4	1567
1972	20.7	.3	1168
1973	20.1	-.3	1158
1974	20.4	.0	1130



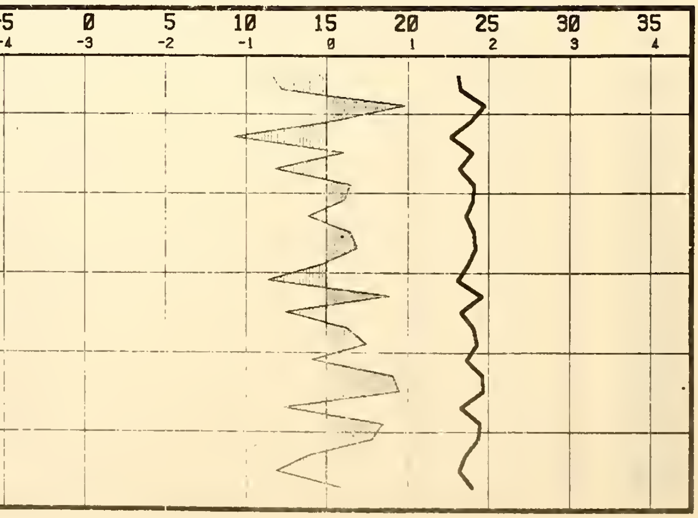
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	18.6	1.0	143
195001	18.2	.6	159
195101	17.2	-.4	274
195201	18.3	.7	309
195301	17.7	.1	394
195401	17.5	-.1	274
195501	17.5	-.1	287
195601	17.7	.1	343
195701	18.2	.6	414
195801	16.4	-1.1	299
195901	17.0	-.6	378
196001	17.1	-.5	473
196101	16.5	-1.1	526
196201	18.2	.6	457
196301	16.8	-.8	323
196401	18.4	.8	326
196501	18.2	.6	340
196601	17.1	-.5	626
196701	17.9	.3	666
196801	18.2	.6	574
196901	16.9	-.7	493
197001	16.4	-1.2	538
197101	17.8	.2	491
197201	18.4	.8	324
197301	17.4	-.2	355
197401	17.8	.2	350



JULAUGSEP

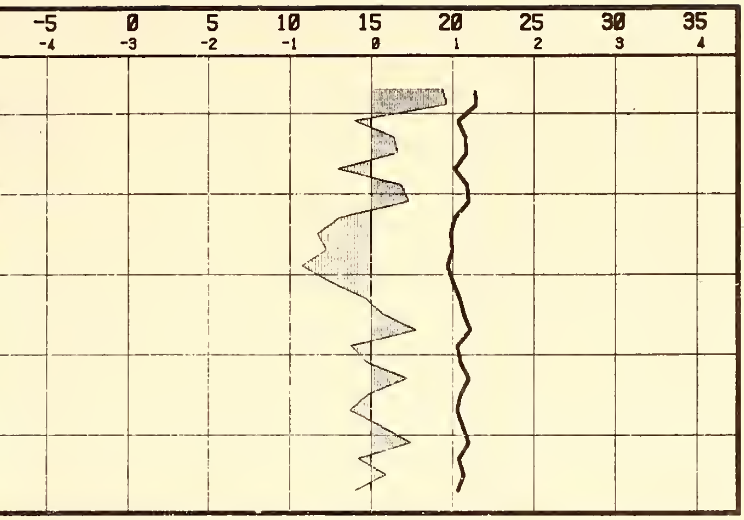
QTR	VALUE	ANOMALY	OBS
194803	23.1	-.7	20
194903	23.2	-.6	36
195003	24.7	1.0	55
195103	23.8	.1	87
195203	22.6	-1.2	95
195303	24.0	.2	194
195403	23.1	-.6	134
195503	24.1	.3	73
195603	24.0	.2	143
195703	23.5	-.2	135
195803	24.1	.3	144
195903	24.1	.4	116
196003	23.7	-.1	133
196103	23.0	-.7	157
196203	24.5	.8	179
196303	23.3	-.5	125
196403	24.0	.3	138
196503	24.3	.5	190
196603	23.6	-.2	336
196703	24.6	.8	425
196803	24.7	.9	554
196903	23.2	-.5	404
197003	24.5	.7	358
197103	24.3	.6	221
197203	23.5	-.2	193
197303	23.1	-.6	188
197403	23.9	.2	253



MSQ 125-2

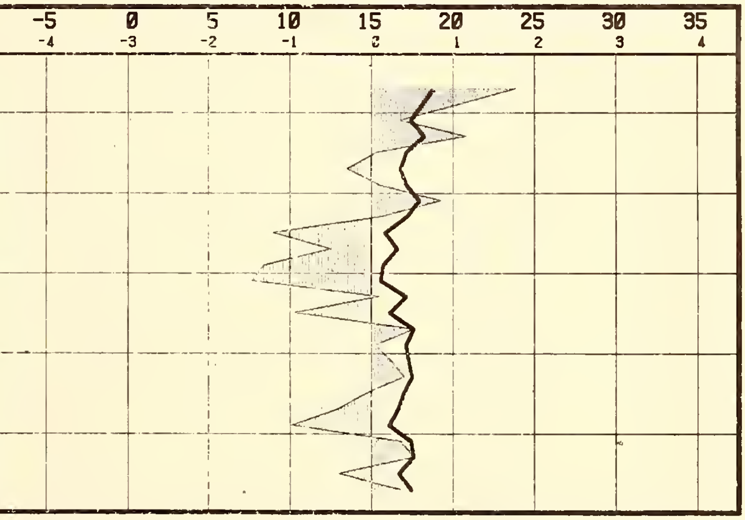
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	21.4	.9	552
1950	21.4	.9	330
1951	20.3	-.2	782
1952	20.8	.3	831
1953	20.8	.3	1282
1954	20.1	-.4	845
1955	20.9	.4	954
1956	20.9	.5	10[illegible]3
1957	20.1	-.4	1134
1958	19.8	-.7	1030
1959	19.9	-.6	1305
1960	19.6	-.9	1236
1961	20.0	-.5	1521
1962	20.4	-.1	1427
1963	20.6	.1	1231
1964	21.0	.5	1255
1965	20.2	-.2	15[illegible]0
1966	20.4	-.1	2432
1967	20.9	.4	26[illegible]1
1968	20.5	-.0	2506
1969	20.2	-.3	2377
1970	20.6	.1	1826
1971	21.0	.5	1653
1972	20.3	-.2	1061
1973	20.7	.2	1070
1974	20.3	-.2	1001



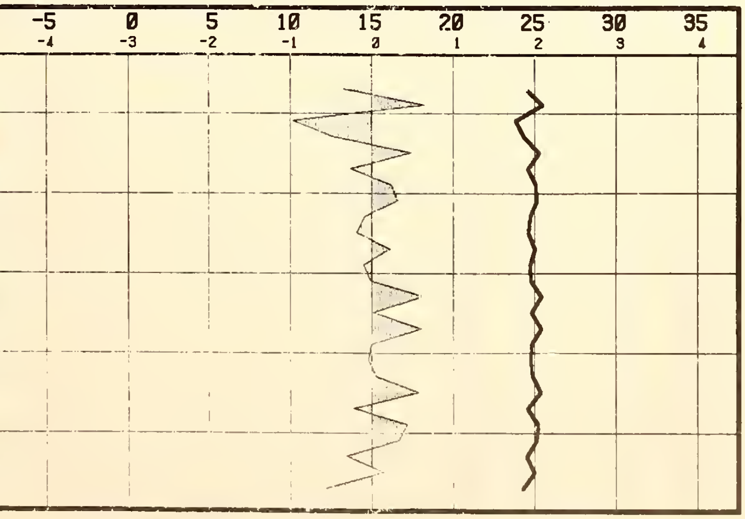
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	18.8	1.8	151
195001	18.1	1.1	134
195101	17.4	.4	234
195201	18.2	1.2	320
195301	17.1	.1	422
195401	16.7	-.3	250
195501	17.1	.1	333
195601	17.9	.8	358
195701	17.2	.1	474
195801	15.8	-1.2	356
195901	16.5	-.5	496
196001	15.7	-1.3	456
196101	15.6	-1.5	597
196201	17.1	.1	432
196301	16.1	-1.0	346
196401	17.5	.5	4[illegible]9
196501	17.1	.0	355
196601	17.3	.2	669
196701	17.4	.4	7[illegible]7
196801	17.0	-.1	438
196901	16.6	-.4	596
197001	16.1	-1.0	505
197101	17.4	.4	436
197201	17.5	.5	239
197301	16.6	-.4	3[illegible]0
197401	17.4	.4	333



JULAUGSEP

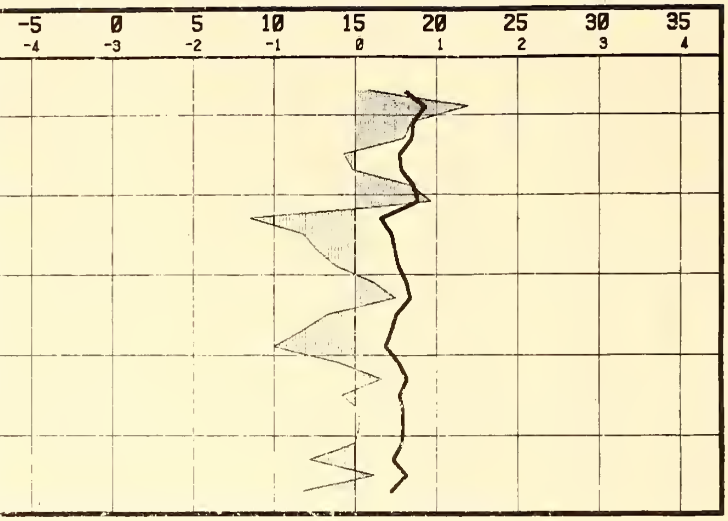
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	24.4	-.4	125
195003	25.4	.6	56
195103	23.8	-1.0	98
195203	24.3	-.5	99
195303	25.3	.5	130
195403	24.5	-.3	142
195503	25.0	.2	98
195603	25.1	.3	1[illegible]2
195703	24.7	-.1	124
195803	24.6	-.2	154
195903	25.0	.2	125
196003	24.7	-.1	191
196103	24.8	-.0	204
196203	25.4	.6	199
196303	24.8	.0	133
196403	25.4	.6	156
196503	24.8	-.0	2[illegible]
196603	24.7	-.0	4[illegible]4
196703	24.8	.1	55[illegible]
196803	25.4	.6	632
196903	24.6	-.2	431
197003	25.2	.4	4[illegible]
197103	25.1	.3	254
197203	24.5	-.3	180
197303	24.9	.1	154
197403	24.2	-.6	193



MSQ 127-3

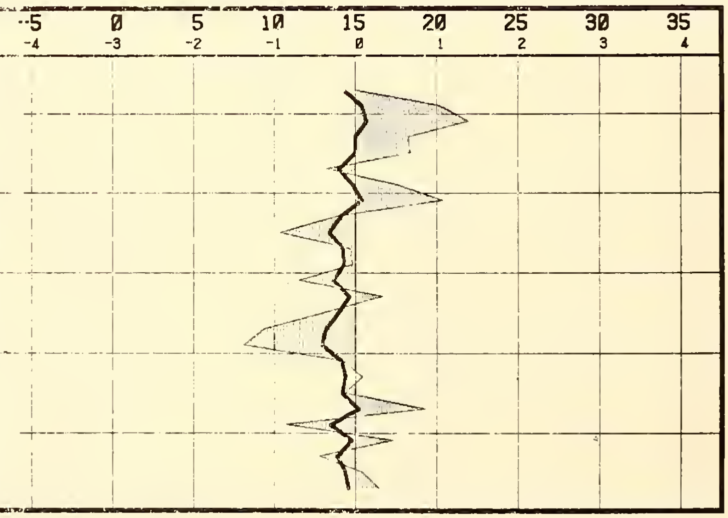
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	18.0	.1	1122
1950	19.2	1.4	417
1951	18.5	.7	436
1952	18.5	.6	530
1953	17.7	-.1	622
1954	17.8	-.0	690
1955	18.6	.7	633
1956	18.8	.9	871
1957	16.6	-1.3	916
1958	17.2	-.6	955
1959	17.4	-.5	1037
1960	17.6	-.2	1067
1961	18.1	.2	1057
1962	18.4	.5	738
1963	17.5	-.3	801
1964	17.2	-.7	1640
1965	16.9	-1.0	1833
1966	17.7	-.2	2134
1967	18.2	.3	1070
1968	17.7	-.2	1134
1969	17.9	.0	950
1970	17.9	.0	911
1971	17.9	-.0	872
1972	17.3	-.6	1161
1973	18.1	.2	1203
1974	17.2	-.6	1329



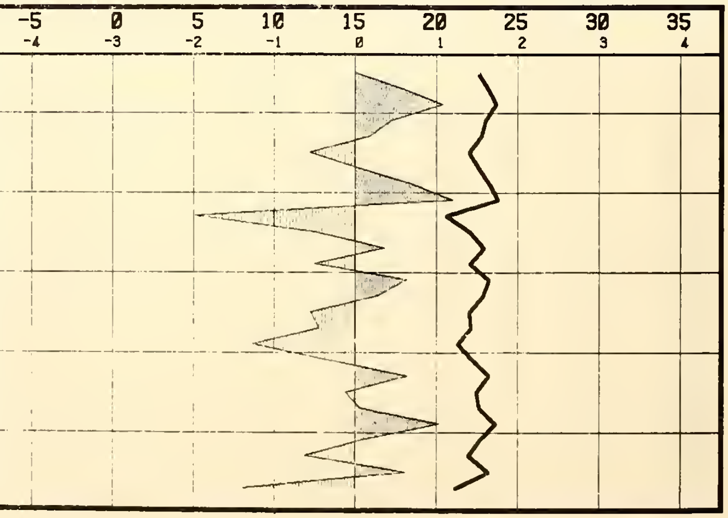
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	14.3	-.0	300
195001	15.3	1.0	87
195101	15.7	1.4	120
195201	14.9	.7	120
195301	15.0	.7	111
195401	13.9	-.4	154
195501	14.8	.5	129
195601	15.4	1.1	149
195701	14.1	-.2	178
195801	13.4	-.9	262
195901	14.2	-.1	238
196001	14.2	-.0	258
196101	13.6	-.7	208
196201	14.6	.3	183
196301	13.9	-.4	167
196401	13.2	-1.1	471
196501	12.9	-1.4	440
196601	14.1	-.2	495
196701	14.4	.1	138
196801	14.2	-.1	148
196901	15.1	.9	145
197001	13.4	-.8	108
197101	14.7	.5	144
197201	13.8	-.4	183
197301	14.4	.1	256
197401	14.6	.3	273



JULAUGSEP

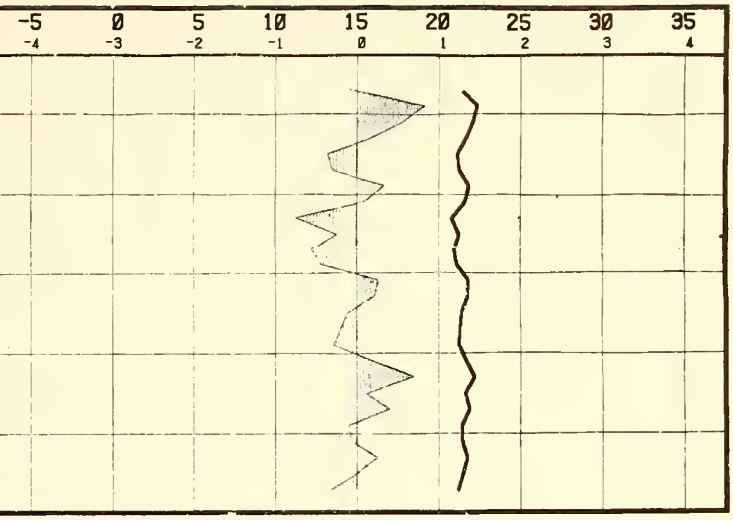
QTR	VALUE	ANOMALY	OBS
194803	22.5	-.0	121
194903	23.1	.6	388
195003	23.6	1.1	155
195103	23.0	.5	97
195203	22.7	.2	138
195303	22.0	-.6	172
195403	22.6	.1	176
195503	23.3	.7	199
195603	23.8	1.2	250
195703	20.6	-2.0	221
195803	22.1	-.5	216
195903	22.9	.4	193
196003	22.1	-.5	212
196103	23.2	.6	197
196203	22.8	.3	248
196303	22.0	-.5	191
196403	22.1	-.4	390
196503	21.3	-1.3	472
196603	22.2	-.3	533
196703	23.2	.6	382
196803	22.4	-.1	388
196903	22.6	.1	388
197003	23.6	1.0	323
197103	22.6	.1	195
197203	21.9	-.6	345
197303	23.2	.6	322
197403	21.2	-1.4	300



MSQ 129-1

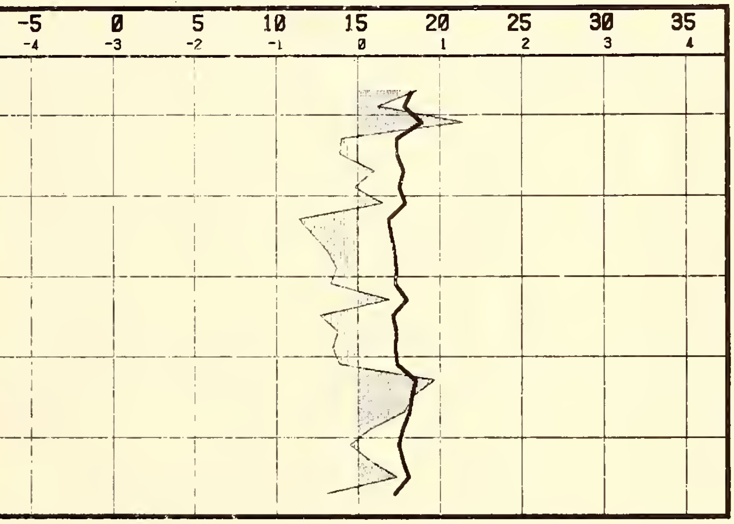
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	21.4	-.1	550
1950	22.3	.8	618
1951	22.0	.6	1138
1952	21.7	.2	1043
1953	21.1	-.4	1410
1954	21.2	-.3	1155
1955	21.8	.3	1344
1956	21.6	.1	1554
1957	20.7	-.7	2006
1958	21.2	-.3	1937
1959	20.9	-.6	2258
1960	21.0	-.4	2537
1961	21.7	.3	2185
1962	21.7	.2	1387
1963	21.4	-.1	1269
1964	21.3	-.2	2949
1965	21.2	-.3	3173
1966	21.7	.2	4301
1967	22.2	.7	2561
1968	21.6	.1	2071
1969	21.9	.4	2036
1970	21.4	-.1	1582
1971	21.4	-.1	1544
1972	21.7	.2	2236
1973	21.5	-.0	2132
1974	21.2	-.3	2100



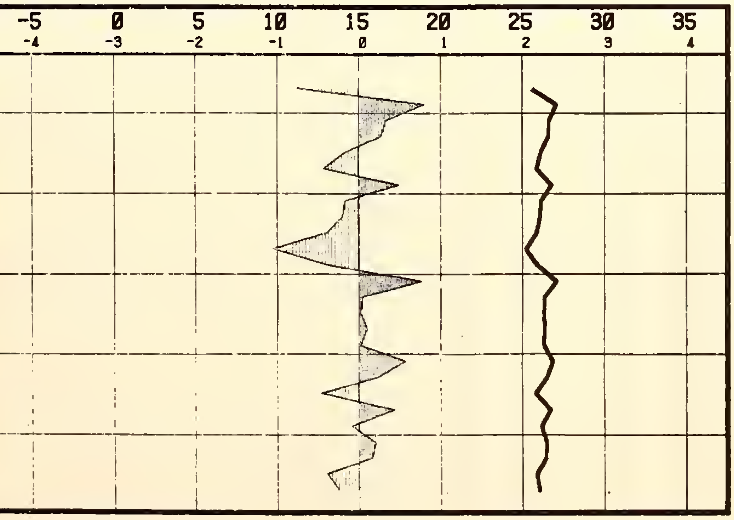
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	18.3	.7	187
195001	17.8	.2	153
195101	18.8	1.3	467
195201	17.4	-.2	378
195301	17.3	-.2	498
195401	17.8	.2	398
195501	17.5	-.0	467
195601	17.9	.3	531
195701	16.8	-.7	751
195801	17.0	-.6	658
195901	17.2	-.4	838
196001	17.3	-.3	900
196101	17.2	-.3	1021
196201	17.9	.4	397
196301	17.1	-.5	336
196401	17.3	-.3	1096
196501	17.3	-.3	890
196601	17.3	-.2	1178
196701	18.5	.9	581
196801	18.2	.7	477
196901	18.1	.6	483
197001	17.7	.1	380
197101	17.5	-.1	327
197201	17.7	.1	636
197301	18.0	.5	902
197401	17.2	-.4	711



JULAUGSEP

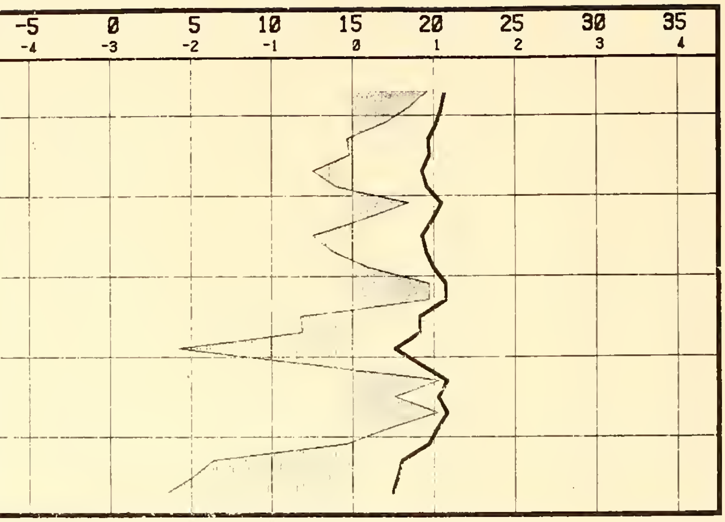
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	25.5	-.8	100
195003	27.1	.8	109
195103	26.6	.3	119
195203	26.5	.3	164
195303	26.1	-.2	254
195403	25.8	-.4	209
195503	26.7	.5	196
195603	26.1	-.2	262
195703	26.1	-.2	289
195803	25.9	-.4	344
195903	25.2	-1.1	303
196003	25.9	-.4	349
196103	27.0	.8	268
196203	26.3	.0	285
196303	26.3	.0	254
196403	26.4	.1	449
196503	26.3	.0	785
196603	26.8	.6	1014
196703	26.5	.2	712
196803	25.8	-.5	486
196903	26.7	.4	567
197003	26.2	-.1	386
197103	26.5	.2	260
197203	26.4	.2	383
197303	25.9	-.4	332
197403	26.0	-.3	392



MSQ 130-3

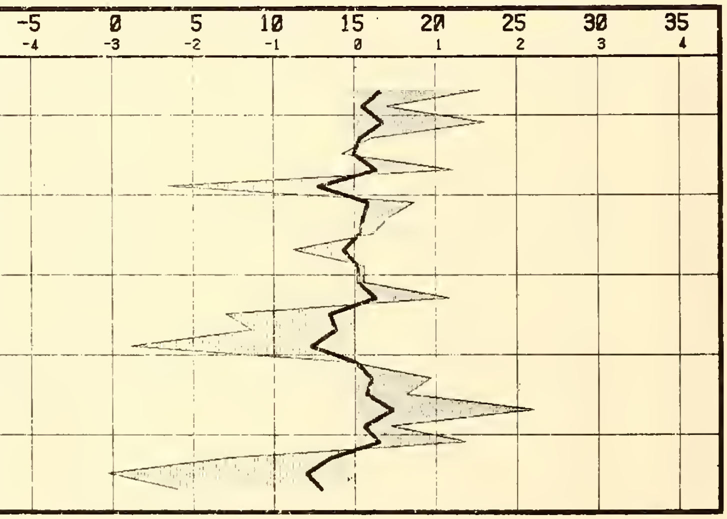
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	20.7	.9	542
1950	20.4	.7	1159
1951	20.1	.4	3206
1952	19.7	-.1	1275
1953	19.7	-.0	1046
1954	19.3	-.5	1102
1955	19.5	-.2	1377
1956	20.4	.7	1458
1957	19.9	.1	1957
1958	19.3	-.5	2007
1959	19.5	-.3	1904
1960	19.9	.2	2135
1961	20.7	.9	1384
1962	20.7	.9	928
1963	19.1	-.6	930
1964	19.1	-.6	2258
1965	17.6	-2.2	1933
1966	19.2	-.6	2235
1967	20.8	1.1	750
1968	20.3	.5	733
1969	20.8	1.0	672
1970	20.2	.4	620
1971	19.7	-.1	930
1972	18.0	-1.7	3218
1973	17.8	-2.0	5336
1974	17.4	-2.3	6730



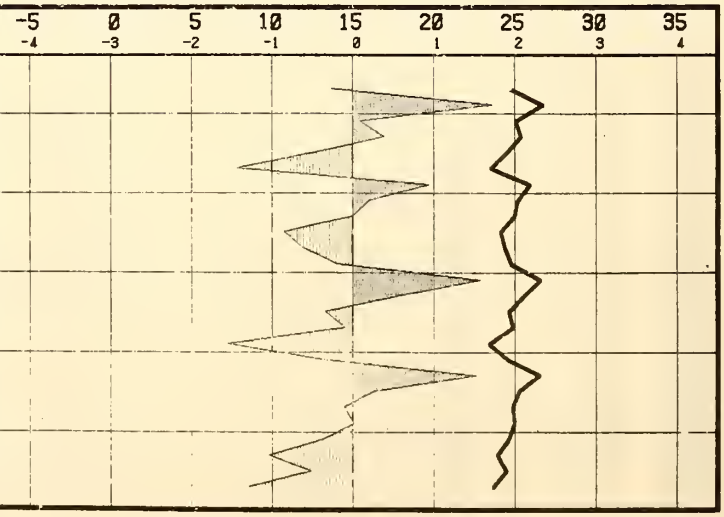
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	16.6	1.6	95
195001	15.5	.4	131
195101	16.7	1.6	1225
195201	15.3	.2	271
195301	14.9	-.1	172
195401	16.3	1.2	163
195501	12.8	-2.3	338
195601	15.8	.7	240
195701	15.5	.4	302
195801	15.3	.2	433
195901	14.3	-.8	436
196001	15.2	.1	455
196101	15.2	.1	329
196201	16.2	1.2	170
196301	13.5	-1.6	240
196401	13.8	-1.3	522
196501	12.3	-2.8	442
196601	15.0	-.0	499
196701	16.0	.9	104
196801	15.7	.6	147
196901	17.3	2.2	95
197001	15.5	.5	99
197101	16.5	1.4	103
197201	13.5	-1.6	653
197301	12.0	-3.1	2424
197401	12.9	-2.2	2831



JULAUGSEP

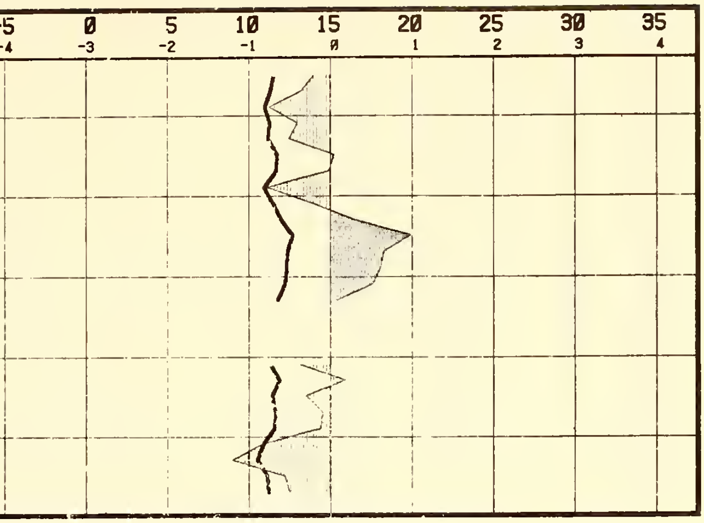
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	24.7	-.3	134
195003	26.7	1.7	214
195103	25.0	.1	286
195203	25.4	.4	353
195303	24.5	-.5	340
195403	23.5	-1.4	428
195503	25.9	.9	376
195603	25.2	.2	427
195703	25.0	.0	740
195803	24.1	-.8	562
195903	24.3	-.6	570
196003	24.8	-.2	640
196103	26.5	1.6	274
196203	25.5	.6	292
196303	24.6	-.3	238
196403	24.9	-.1	625
196503	23.4	-1.6	593
196603	24.6	-.4	638
196703	26.5	1.5	251
196803	25.2	.3	227
196903	24.9	-.1	235
197003	25.0	.0	222
197103	24.6	-.4	124
197203	23.9	-1.0	613
197303	24.4	-.5	502
197403	23.7	-1.3	744



MSQ 157-4

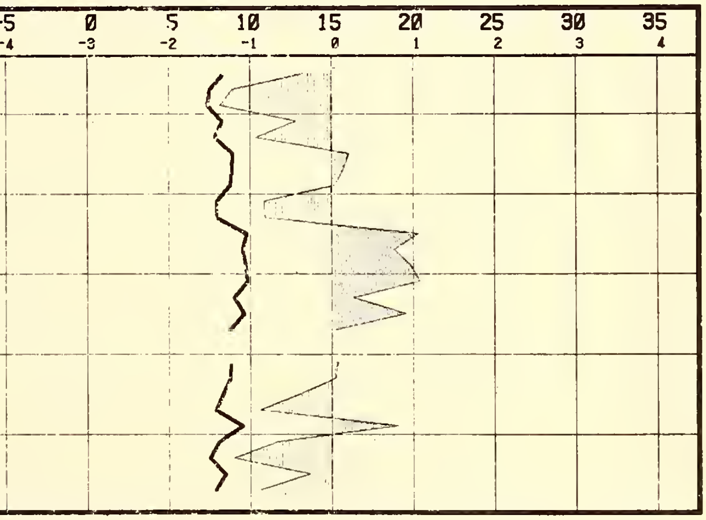
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	11.5	-.2	514
1949	11.3	-.4	699
1950	10.9	-.8	539
1951	11.3	-.4	944
1952	11.2	-.5	677
1953	11.7	.0	671
1954	11.7	-.0	699
1955	10.9	-.9	1175
1956	11.5	-.2	1176
1957	12.0	.3	1341
1958	12.7	1.0	1250
1959	12.3	.6	1141
1960	12.3	.6	2122
1961	12.2	.5	1146
1962	11.8	.1	1018
1963	INSUF DATA		
1964	INSUF DATA		
1965	INSUF DATA		
1966	11.3	-.4	1410
1967	11.9	.2	2858
1968	11.4	-.3	3850
1969	11.6	-.1	1731
1970	11.6	-.1	1613
1971	10.8	-.8	1557
1972	10.5	-1.2	2730
1973	11.1	-.6	1376
1974	11.2	-.5	1813



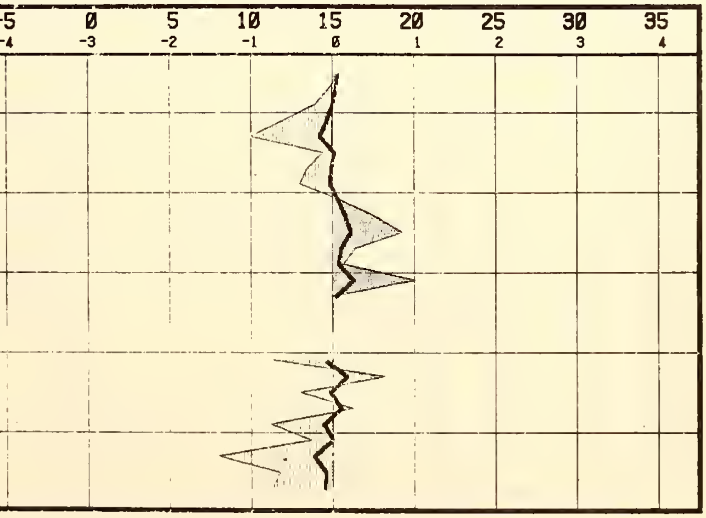
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	8.4	-.3	41
194901	7.5	-1.2	118
195001	7.3	-1.4	193
195101	8.3	-.4	216
195201	7.8	-.9	139
195301	8.9	.2	159
195401	8.9	.1	152
195501	8.8	.0	164
195601	7.3	-.8	220
195701	7.9	-.8	257
195801	9.8	1.1	352
195901	9.5	.8	334
196001	9.7	1.0	348
196101	9.8	1.1	336
196201	9.0	.3	255
196301	9.6	.9	259
196401	8.8	.1	56
196501	INSUF DATA		
196601	8.8	.1	207
196701	8.8	.0	537
196801	8.3	-.4	597
196901	7.8	-.9	371
197001	9.5	.8	399
197101	8.1	-.7	397
197201	7.5	-1.2	223
197301	8.4	-.3	330
197401	7.8	-.9	274



JULAUGSEP

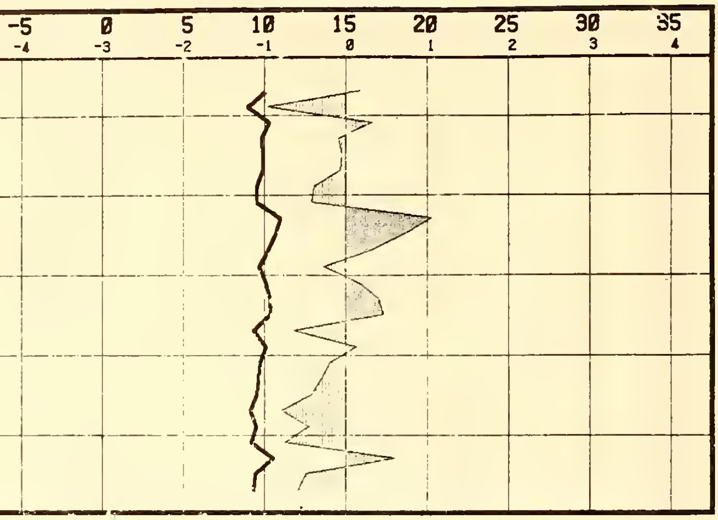
QTR	VALUE	ANOMALY	OBS
194803	15.3	.1	79
194903	15.2	-.0	257
195003	15.0	-.2	111
195103	14.6	-.6	208
195203	14.2	-1.0	133
195303	15.1	-.1	156
195403	14.9	-.3	178
195503	14.8	-.4	421
195603	15.3	.1	402
195703	15.8	.5	393
195803	16.1	.8	319
195903	15.5	.3	256
196003	15.4	.1	518
196103	16.2	1.0	297
196203	15.2	-.0	250
196303	INSUF DATA		
196403	14.1	-1.2	25
196503	INSUF DATA		
196603	14.5	-.7	650
196703	15.9	.6	840
196803	14.8	-.4	1906
196903	15.5	.2	513
197003	14.5	-.8	436
197103	15.0	-.3	322
197203	13.8	-1.4	1142
197303	14.6	-.7	338
197403	14.5	-.7	836



MSQ 159-3

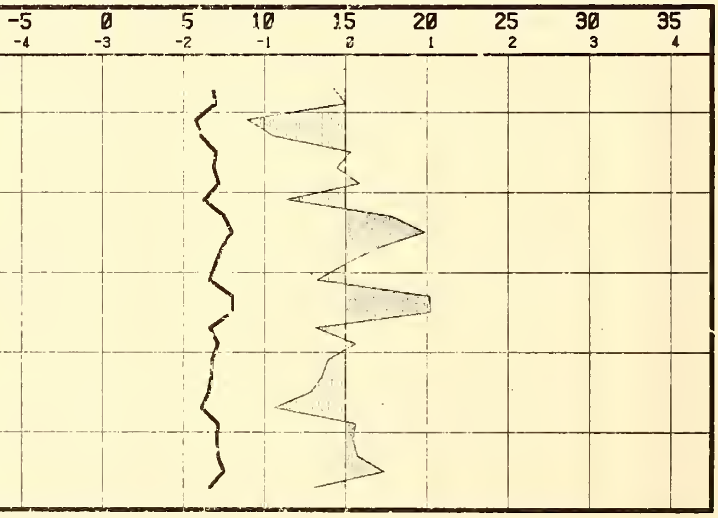
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	10.1	.2	450
1950	9.0	-1.0	409
1951	10.2	.3	423
1952	9.8	-.1	476
1953	9.9	-.0	513
1954	9.8	-.1	610
1955	9.5	-.4	592
1956	9.5	-.4	757
1957	11.0	1.1	879
1958	10.6	.7	855
1959	10.2	.3	735
1960	9.6	-.3	871
1961	10.1	.2	819
1962	10.3	.4	932
1963	10.4	.5	1006
1964	9.3	-.6	1024
1965	10.0	.1	1134
1966	9.7	-.2	1350
1967	9.6	-.3	1557
1968	9.5	-.4	1874
1969	9.1	-.8	1311
1970	9.5	-.5	1256
1971	9.2	-.8	1220
1972	10.5	.6	734
1973	9.4	-.5	1040
1974	9.3	-.6	977



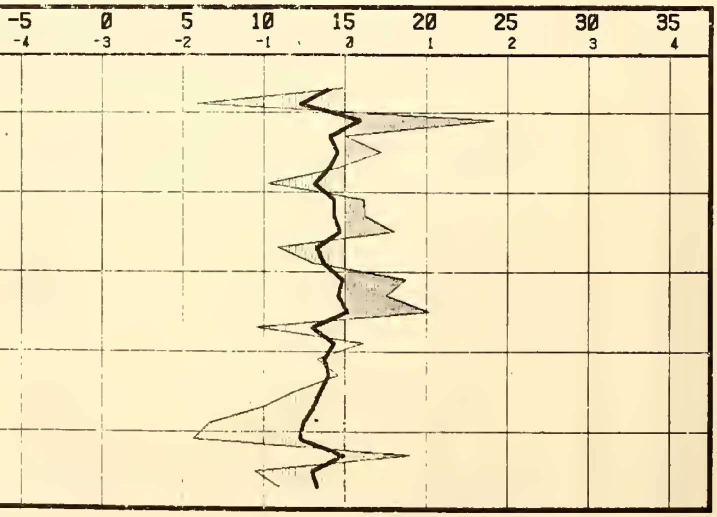
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	6.8	-.2	107
195001	7.0	-.0	102
195101	5.8	-1.2	92
195201	6.1	-.9	110
195301	7.0	.1	99
195401	6.9	-.1	128
195501	7.1	.2	118
195601	6.2	-.7	147
195701	7.5	.6	143
195801	7.9	1.0	155
195901	7.4	.4	175
196001	7.0	.0	130
196101	6.6	-.3	135
196201	8.0	1.0	239
196301	8.0	1.0	252
196401	6.6	-.4	259
196501	7.1	.1	255
196601	6.7	-.2	357
196701	6.7	-.3	296
196801	6.5	-.4	434
196901	6.1	-.9	327
197001	7.1	.1	239
197101	7.1	.1	234
197201	7.1	.1	151
197301	7.4	.5	226
197401	6.6	-.4	222



JULAUGSEP

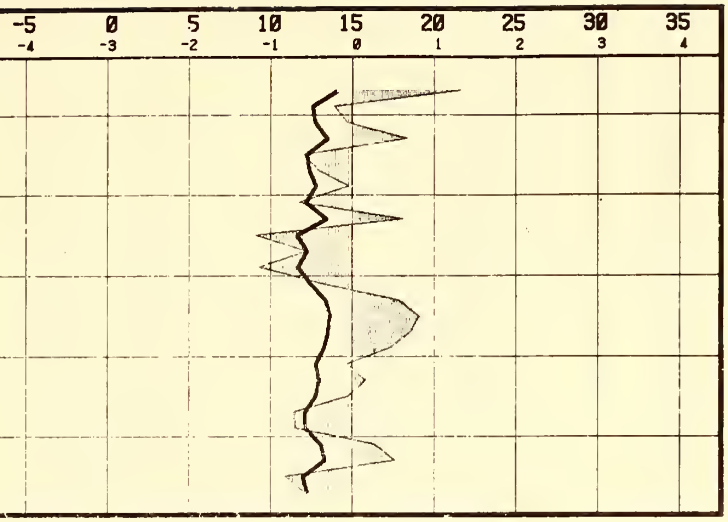
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	14.0	-.0	112
195003	12.2	-1.8	84
195103	15.9	1.8	130
195203	14.1	-.0	142
195303	14.5	.4	139
195403	14.0	-.1	170
195503	13.1	-1.0	184
195603	14.3	.2	204
195703	14.3	.2	296
195803	14.7	.6	229
195903	13.2	-.8	211
196003	13.7	-.4	257
196103	14.8	.7	210
196203	14.6	.5	248
196303	15.1	1.0	213
196403	13.0	-1.1	244
196503	14.3	.2	235
196603	13.7	-.3	297
196703	14.0	-.1	402
196803	13.5	-.6	497
196903	13.0	-1.0	370
197003	12.4	-1.7	354
197103	12.2	-1.9	222
197203	14.9	.8	174
197303	13.0	-1.1	239
197403	13.2	-.8	256



MSQ 160-2

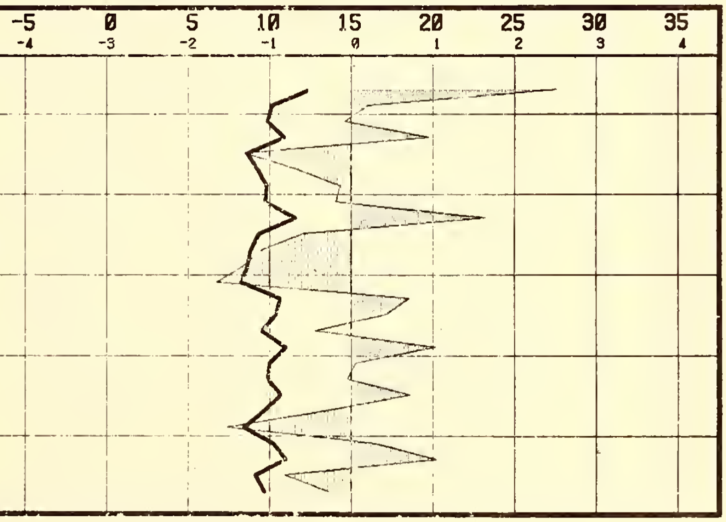
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	14.1	1.3	337
1950	12.6	-.2	225
1951	12.7	-.1	417
1952	13.5	.7	403
1953	12.2	-.6	364
1954	12.4	-.4	387
1955	12.7	-.1	351
1956	12.1	-.6	538
1957	13.4	.6	659
1958	11.6	-1.2	742
1959	12.2	-.6	810
1960	11.7	-1.1	878
1961	12.4	-.4	951
1962	13.4	.6	950
1963	13.6	.8	1119
1964	13.5	.7	963
1965	13.3	.5	1018
1966	12.7	-.1	1139
1967	12.9	.2	1312
1968	12.7	-.0	1319
1969	12.1	-.7	1337
1970	12.1	-.7	1131
1971	13.1	.3	955
1972	13.3	.5	695
1973	12.0	-.8	650
1974	12.2	-.6	732



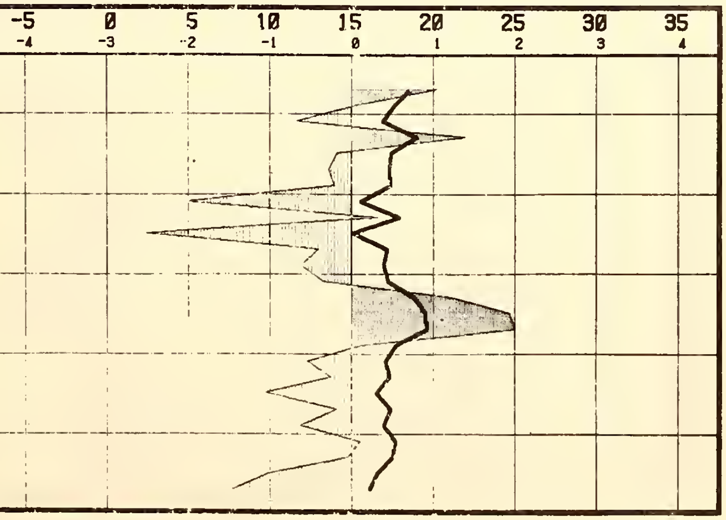
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	12.4	2.5	50
195001	10.1	.2	43
195101	9.8	-.1	70
195201	10.9	.9	91
195301	8.6	-1.3	54
195401	9.3	-.7	85
195501	9.8	-.1	67
195601	9.7	-.2	114
195701	11.6	1.6	149
195801	9.3	-.6	139
195901	8.8	-1.1	250
196001	8.6	-1.3	206
196101	8.3	-1.6	133
196201	10.6	.7	226
196301	10.3	.4	267
196401	9.5	-.4	157
196501	10.9	1.0	157
196601	10.0	.1	231
196701	9.9	-.0	250
196801	10.6	.7	234
196901	9.6	-.3	217
197001	8.4	-1.5	153
197101	10.2	.3	200
197201	11.0	1.0	119
197301	9.1	-.8	120
197401	9.6	-.3	136



JULAUGSEP

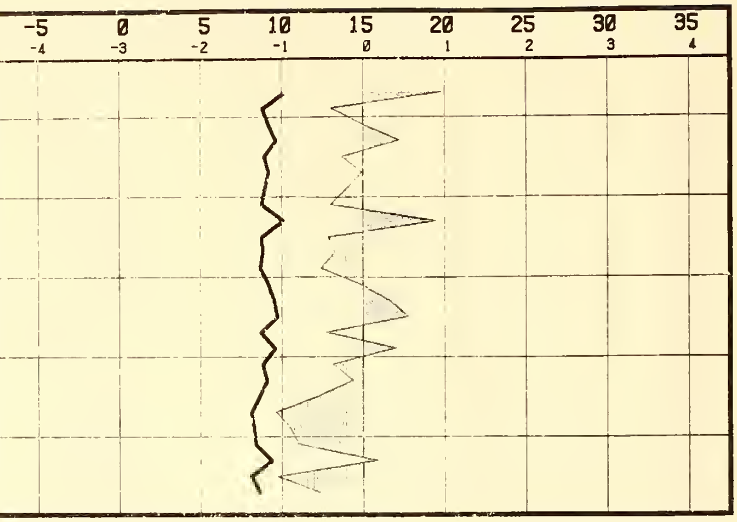
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	18.6	1.1	84
195003	17.6	.0	87
195103	16.9	-.7	153
195203	19.0	1.4	103
195303	17.4	-.2	122
195403	17.3	-.3	128
195503	17.4	-.2	89
195603	15.5	-2.0	139
195703	17.9	.3	158
195803	15.1	-2.5	228
195903	17.2	-.4	204
196003	17.0	-.6	228
196103	17.2	-.4	315
196203	18.8	1.2	279
196303	19.5	1.9	310
196403	19.6	2.0	329
196503	17.7	.1	[illegible]
196603	17.0	-.5	339
196703	17.3	-.3	458
196803	16.5	-1.1	432
196903	17.4	-.2	434
197003	16.9	-.6	385
197103	17.7	.1	234
197203	17.5	-.1	220
197303	16.6	-1.0	134
197403	16.1	-1.5	217



MSQ 160-3

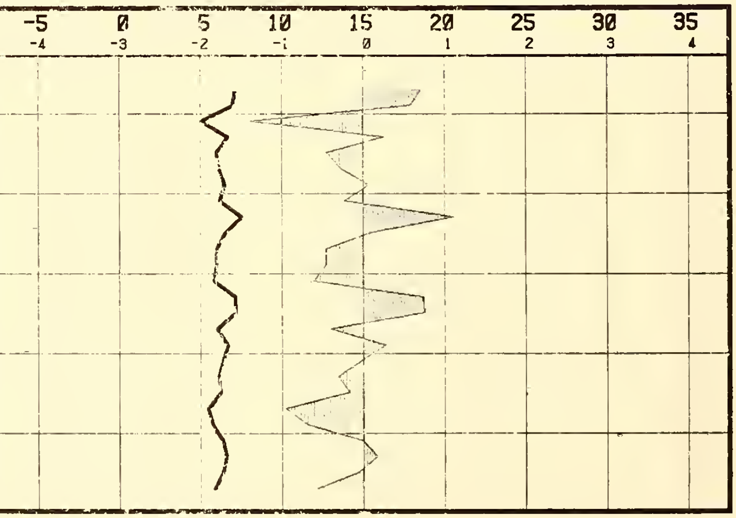
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	10.1	1.0	302
1950	8.8	-.4	265
1951	9.1	-.0	540
1952	9.6	.4	5[illegible]0
1953	8.9	-.3	607
1954	9.1	-.0	556
1955	9.0	-.2	683
1956	8.8	-.4	879
1957	10.1	.9	936
1958	8.7	-.4	1168
1959	8.8	-.3	1154
1960	8.6	-.5	13[illegible]1
1961	9.1	-.0	1058
1962	9.5	.3	12[illegible]9
1963	9.7	.5	1325
1964	8.7	-.4	1123
1965	9.6	.4	1257
1966	8.8	-.4	1268
1967	9.0	-.1	1492
1968	8.6	-.6	17[illegible]4
1969	8.1	-1.1	1229
1970	8.3	-.9	11[illegible]9
1971	8.4	-.8	1083
1972	9.3	.2	641
1973	8.1	-1.0	834
1974	8.6	-.5	748



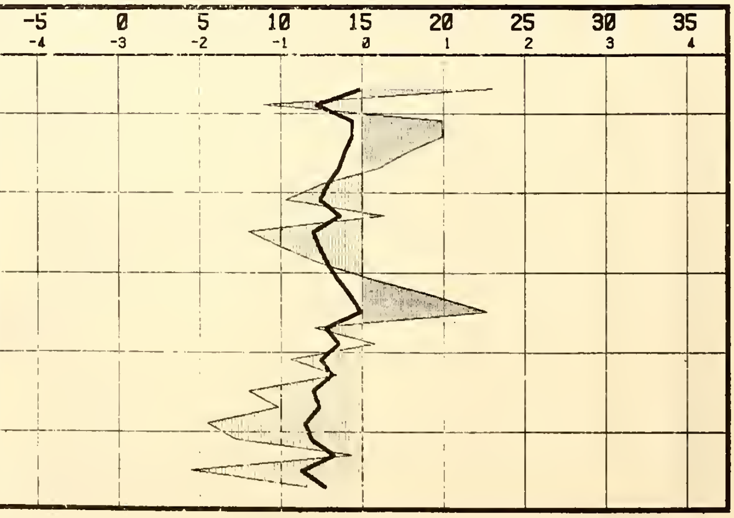
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	7.1	.7	32
195001	7.0	.6	53
195101	5.0	-1.4	72
195201	6.6	.2	103
195301	5.9	-.4	98
195401	6.1	-.3	89
195501	6.5	.1	1[illegible]9
195601	6.2	-.2	130
195701	7.5	1.1	174
195801	6.5	.1	188
195901	5.9	-.5	2[illegible]0
196001	5.9	-.5	258
196101	5.8	-.6	230
196201	7.1	.7	243
196301	7.1	.8	301
196401	6.0	-.4	251
196501	6.7	.3	234
196601	6.4	-.0	308
196701	6.1	-.3	278
196801	6.2	-.2	435
196901	5.4	-.9	285
197001	5.7	-.7	2[illegible]7
197101	6.4	-.0	287
197201	6.6	.2	123
197301	6.3	-.1	159
197401	5.8	-.6	134



JULAUGSEP

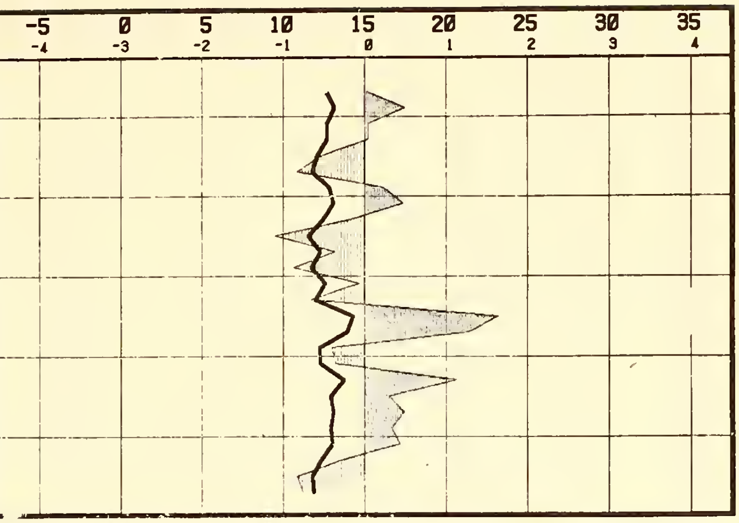
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	15.0	1.6	104
195003	12.1	-1.2	73
195103	14.3	1.0	2[illegible]8
195203	14.3	1.0	167
195303	13.9	.6	2[illegible]0
195403	13.6	.2	175
195503	12.9	-.5	230
195603	12.4	-.9	232
195703	13.6	.3	3[illegible]5
195803	11.9	-1.4	331
195903	12.4	-1.0	354
196003	12.9	-.5	452
196103	13.5	.2	358
196203	14.2	.9	367
196303	14.9	1.5	339
196403	12.8	-.6	285
196503	13.5	.1	339
196603	12.5	-.9	326
196703	13.0	-.3	384
196803	11.9	-1.4	433
196903	12.3	-1.0	363
197003	11.4	-1.9	3[illegible]1
197103	11.8	-1.6	159
197203	13.2	-.1	167
197303	11.2	-2.1	194
197403	12.7	-.7	172



MSQ 162-1

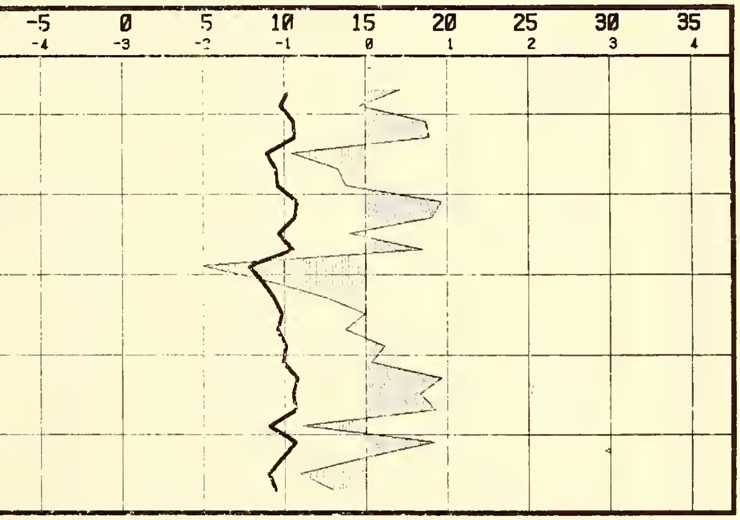
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	12.6	.0	258
1950	13.1	.5	207
1951	12.6	.0	336
1952	12.6	.0	355
1953	12.0	-.5	344
1954	11.8	-.8	345
1955	12.8	.2	373
1956	13.1	.5	576
1957	12.4	-.2	652
1958	11.5	-1.1	630
1959	12.2	-.4	1842
1960	11.7	-.9	2041
1961	12.5	-.1	1539
1962	11.9	-.7	1915
1963	14.2	1.6	1459
1964	13.9	1.3	2197
1965	12.2	-.4	1419
1966	12.2	-.4	1150
1967	13.7	1.1	432
1968	12.9	.3	518
1969	13.1	.5	408
1970	12.9	.3	441
1971	13.0	.4	339
1972	12.3	-.3	632
1973	11.8	-.8	659
1974	11.8	-.8	714



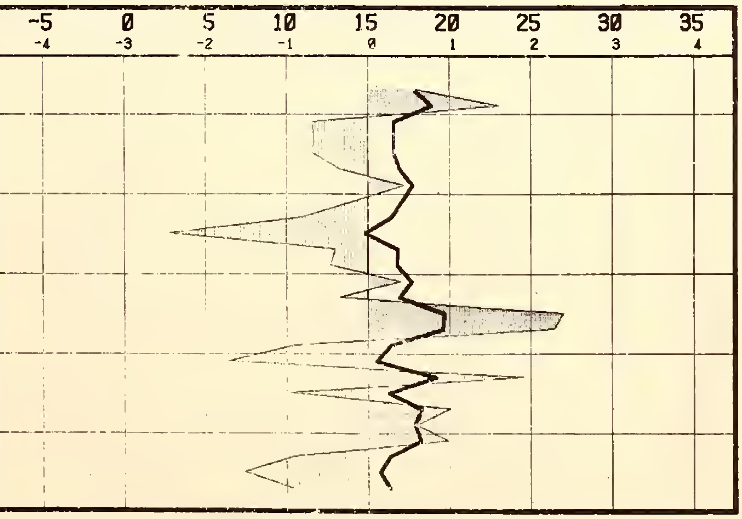
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	10.2	.4	38
195001	9.7	-.1	43
195101	10.6	.7	43
195201	10.6	.8	32
195301	8.9	-.9	51
195401	9.5	-.3	78
195501	9.6	-.3	57
195601	10.7	.9	124
195701	10.6	.8	129
195801	9.6	-.2	160
195901	10.5	.7	435
196001	7.8	-2.0	555
196101	8.6	-1.2	326
196201	9.3	-.5	356
196301	9.8	-.0	382
196401	9.6	-.3	517
196501	10.0	.2	446
196601	9.9	.1	204
196701	10.7	.9	56
196801	10.5	.7	38
196901	10.7	.8	53
197001	9.0	-.8	46
197101	10.7	.8	48
197201	9.8	-.0	37
197301	9.0	-.8	109
197401	9.4	-.4	126



JULAUGSEP

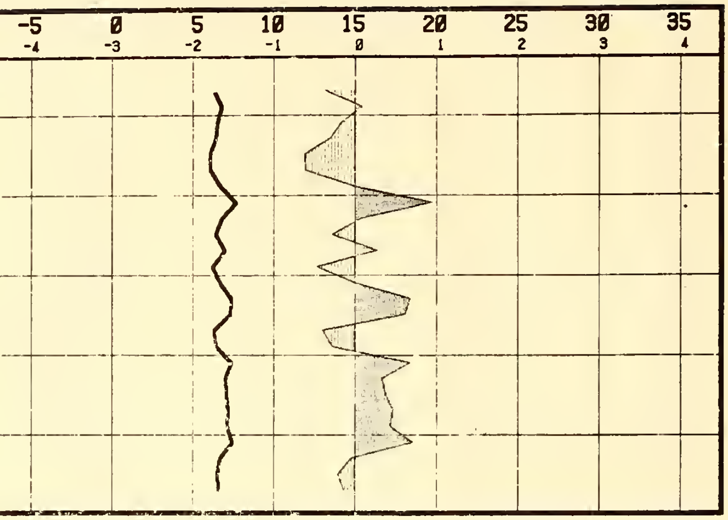
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	17.8	.6	32
195003	18.8	1.6	31
195103	16.6	-.7	125
195203	16.6	-.7	90
195303	16.6	-.7	115
195403	16.9	-.3	118
195503	17.7	.4	110
195603	17.1	-.2	156
195703	16.4	-.8	155
195803	14.8	-2.4	131
195903	16.8	-.4	458
196003	16.8	-.5	506
196103	17.6	.4	448
196203	16.9	-.3	489
196303	19.6	2.4	426
196403	19.5	2.3	528
196503	16.3	-.9	384
196603	15.5	-1.7	347
196703	19.1	1.9	224
196803	16.3	-1.0	151
196903	18.2	1.0	155
197003	17.8	.6	174
197103	18.2	1.0	64
197203	16.3	-.9	205
197303	15.7	-1.5	178
197403	16.3	-.9	202



MSQ 163-3

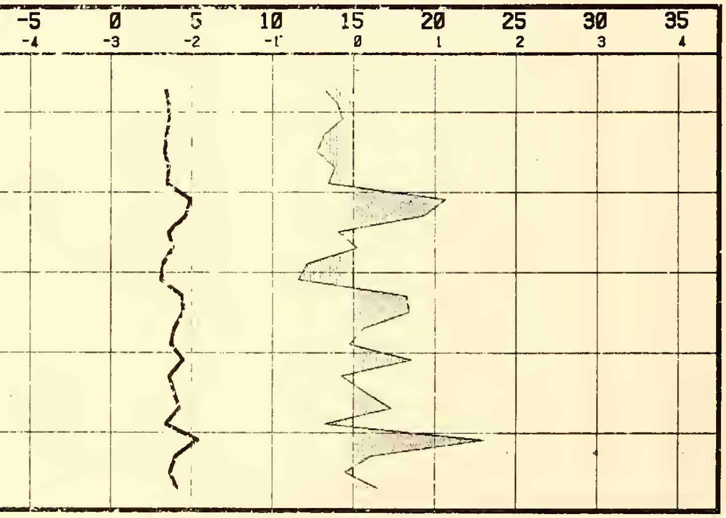
YEAR

YEAR	VALUE	ANOMALY	C3S
1948	INSUF DATA		
1949	6.3	-.4	434
1950	6.8	.1	429
1951	6.5	-.2	737
1952	6.4	-.3	775
1953	6.1	-.6	871
1954	6.1	-.6	912
1955	6.7	-.0	1471
1956	7.6	.9	1750
1957	6.8	.1	2033
1958	6.4	-.3	2631
1959	7.0	.3	2913
1960	6.2	-.5	2747
1961	6.7	-.0	1431
1962	7.4	.7	617
1963	7.3	.6	578
1964	6.3	-.4	3614
1965	6.4	-.3	3228
1966	7.4	.7	805
1967	7.0	.3	378
1968	7.1	.4	508
1969	7.2	.5	318
1970	7.1	.4	226
1971	7.4	.7	526
1972	6.6	-.0	1257
1973	6.5	-.2	1622
1974	6.5	-.1	1399



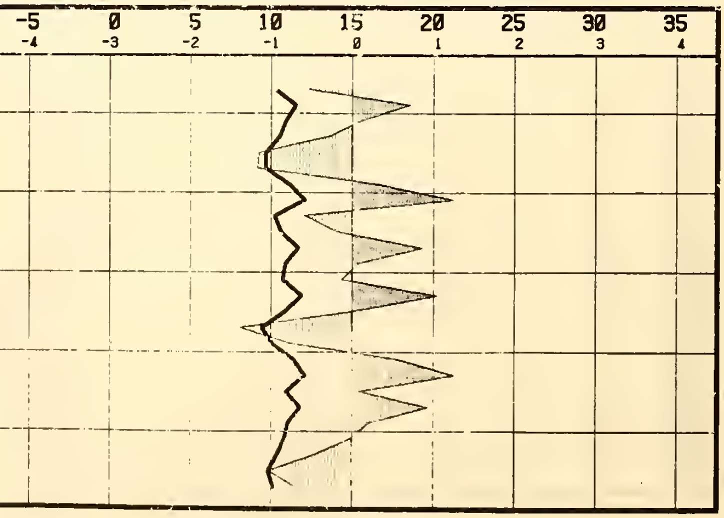
JANFEBMAR

QTR	VALUE	ANOMALY	C3S
194801	INSUF DATA		
194901	3.4	-.4	57
195001	3.6	-.2	71
195101	3.6	-.1	120
195201	3.4	-.4	136
195301	3.3	-.5	94
195401	3.5	-.2	123
195501	3.4	-.3	210
195601	4.9	1.1	247
195701	4.6	.9	237
195801	3.6	-.2	251
195901	3.8	.0	426
196001	3.2	-.6	434
196101	3.1	-.7	390
196201	4.4	.6	102
196301	4.4	.7	136
196401	3.9	.1	622
196501	3.7	-.1	650
196601	4.5	.7	201
196701	3.6	-.2	48
196801	3.9	.1	89
196901	4.2	.5	40
197001	3.4	-.4	34
197101	5.4	1.6	29
197201	4.0	.2	211
197301	3.7	-.1	320
197401	4.1	.3	233



JULAUGSEP

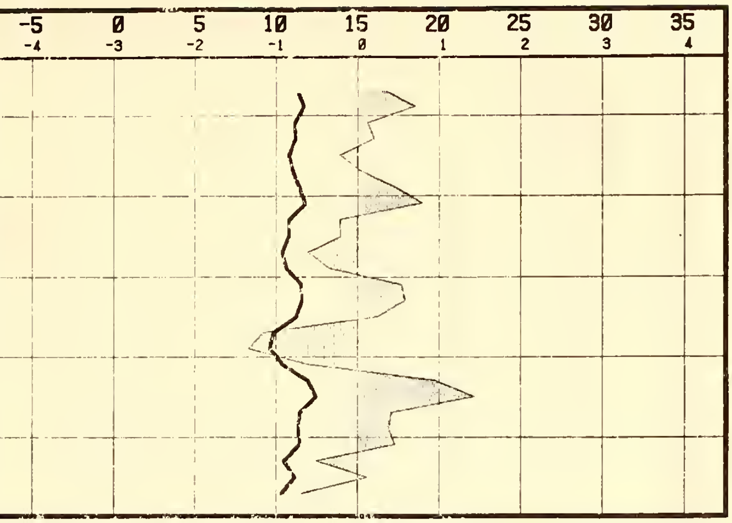
QTR	VALUE	ANOMALY	C3S
194803	INSUF DATA		
194903	10.3	-.5	150
195003	11.5	.7	97
195103	10.9	.1	289
195203	10.5	-.3	244
195303	9.7	-1.2	315
195403	9.6	-1.2	305
195503	11.1	.3	415
195603	12.0	1.2	638
195703	10.2	-.6	736
195803	10.6	-.2	833
195903	11.7	.9	973
196003	10.9	.1	939
196103	10.7	-.1	221
196203	11.8	1.0	198
196303	10.8	-.0	155
196403	9.4	-1.4	1153
196503	10.0	-.8	957
196603	11.4	.6	210
196703	12.1	1.2	142
196803	10.9	.1	123
196903	11.7	.9	[illegible]
197003	11.0	.2	32
197103	10.8	-.0	42
197203	10.3	-.5	356
197303	9.8	-1.0	397
197403	10.1	-.7	427



MSQ 165-2

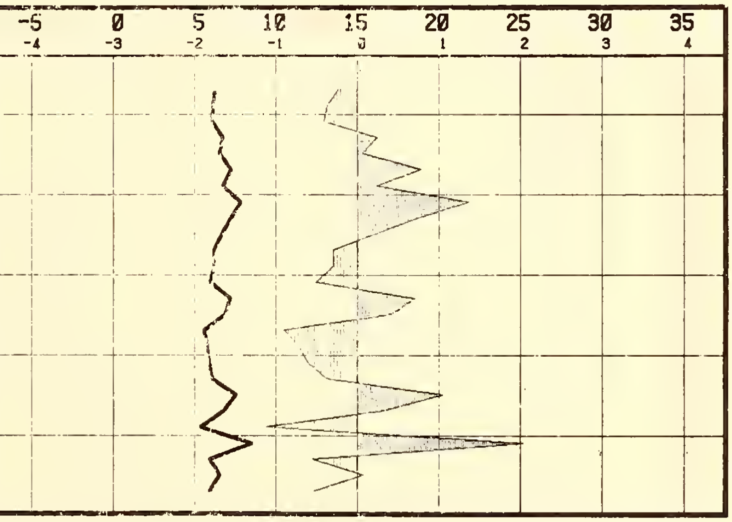
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	11.3	.3	430
1950	11.7	.7	482
1951	11.1	.1	823
1952	11.2	.2	820
1953	10.7	-.2	952
1954	11.0	.0	920
1955	11.4	.5	1406
1956	11.8	.8	2030
1957	10.7	-.2	2755
1958	10.8	-.2	3638
1959	10.4	-.6	3543
1960	10.6	-.4	4087
1961	11.5	.5	2145
1962	11.5	.6	832
1963	11.2	.2	838
1964	9.8	-1.2	5254
1965	9.6	-1.3	5363
1966	10.3	-.6	4974
1967	11.9	.9	471
1968	12.4	1.4	637
1969	11.4	.4	434
1970	11.3	.4	363
1971	11.4	.5	730
1972	10.5	-.5	1959
1973	11.1	.1	2291
1974	10.3	-.7	2275



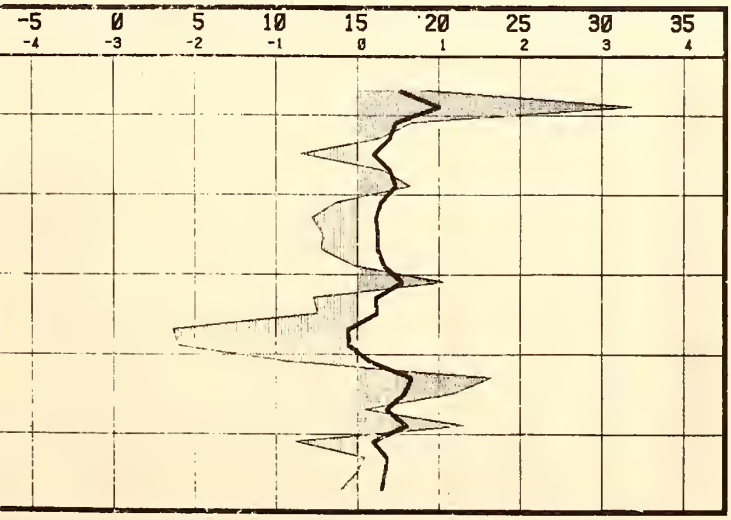
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	6.2	-.2	57
195001	6.1	-.4	109
195101	6.0	-.4	117
195201	6.7	.2	175
195301	6.5	.1	149
195401	7.2	.8	159
195501	6.7	.2	242
195601	7.8	1.4	292
195701	7.2	.7	442
195801	6.7	.2	438
195901	6.1	-.3	630
196001	6.2	-.3	728
196101	5.9	-.5	634
196201	7.1	.7	159
196301	6.9	.4	138
196401	5.6	-.9	947
196501	5.7	-.7	1046
196601	5.8	-.6	1030
196701	6.1	-.4	57
196801	7.5	1.0	106
196901	6.8	.3	38
197001	5.3	-1.1	59
197101	8.5	2.0	28
197201	5.9	-.6	371
197301	6.5	.1	423
197401	5.9	-.5	409



JULAUGSEP

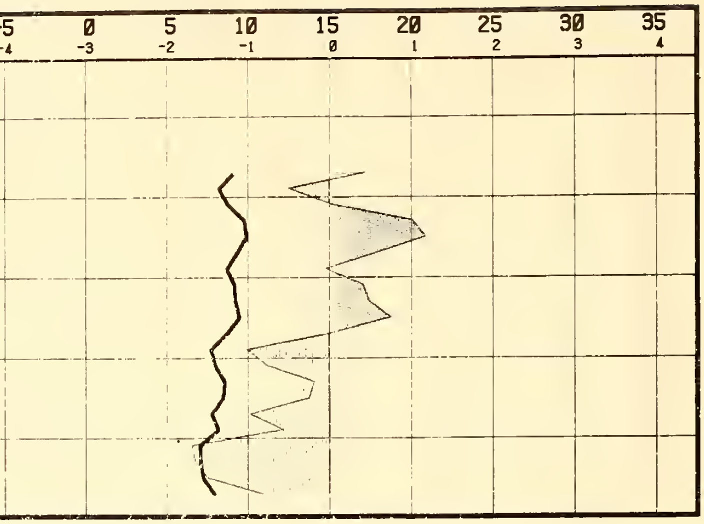
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	17.5	.8	153
195003	20.0	3.4	1.6
195103	17.3	.7	385
195203	16.9	.3	251
195303	16.0	-.7	375
195403	17.0	.3	338
195503	17.3	.6	432
195603	16.4	-.2	736
195703	16.1	-.6	926
195803	16.2	-.4	1208
195903	16.2	-.4	1254
196003	16.6	-.0	1332
196103	17.7	1.0	238
196203	16.1	-.5	290
196303	16.2	-.5	254
196403	14.4	-2.3	1460
196503	14.4	-2.2	1372
196603	15.8	-.8	1330
196703	18.3	1.6	138
196803	17.8	1.2	132
196903	16.7	.1	200
197003	18.0	1.3	133
197103	15.9	-.8	54
197203	16.7	.1	621
197303	16.6	-.0	531
197403	16.5	-.2	659



MSQ 195-3

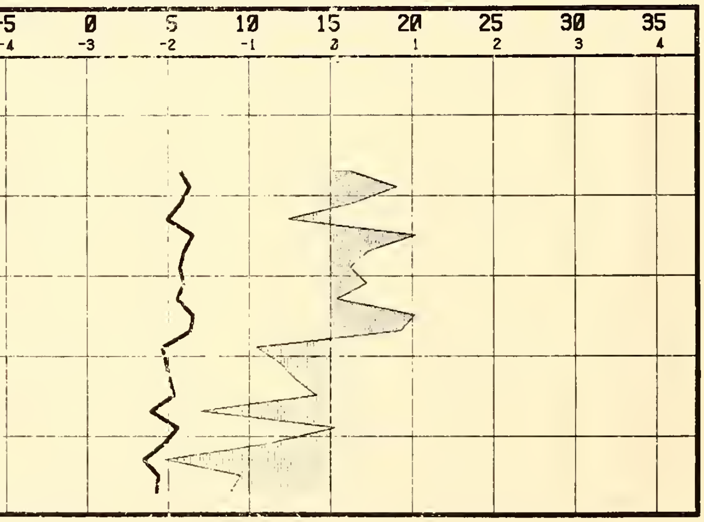
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	INSUF DATA		
1950	INSUF DATA		
1951	INSUF DATA		
1952	INSUF DATA		
1953	INSUF DATA		
1954	9.2	.4	157
1955	8.2	-.5	135
1956	8.8	.0	274
1957	9.7	1.0	254
1958	9.9	1.2	360
1959	9.3	.6	257
1960	8.7	-.0	347
1961	9.1	.4	430
1962	9.2	.5	729
1963	9.5	.7	731
1964	8.7	-.0	728
1965	7.7	-1.0	821
1966	8.0	-.8	933
1967	8.5	-.2	1256
1968	8.5	-.3	1100
1969	7.8	-1.0	773
1970	8.1	-.6	992
1971	7.0	-1.7	856
1972	7.1	-1.7	757
1973	7.2	-1.5	538
1974	7.9	-.8	632



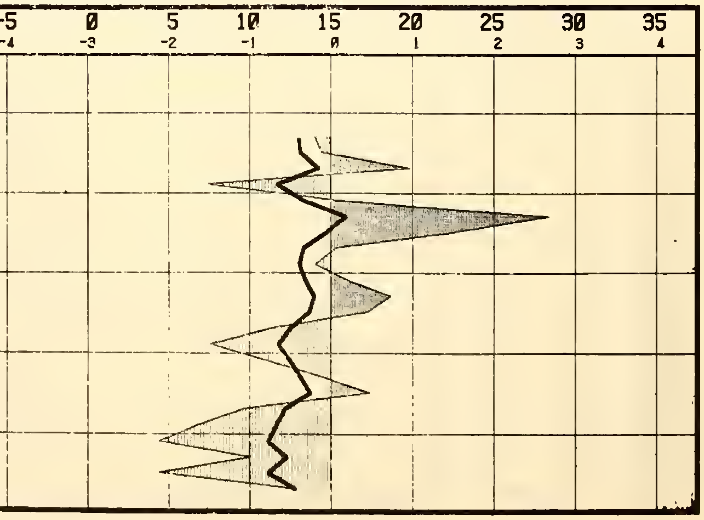
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	2.8	-2.7	32
195001	INSUF DATA		
195101	INSUF DATA		
195201	INSUF DATA		
195301	INSUF DATA		
195401	5.7	.2	28
195501	6.3	.8	37
195601	5.8	.3	41
195701	5.0	-.5	65
195801	6.5	1.0	33
195901	6.0	.5	67
196001	5.7	.2	79
196101	5.9	.4	33
196201	5.6	.1	144
196301	6.5	1.0	175
196401	6.3	.9	129
196501	4.6	-.9	176
196601	4.9	-.6	137
196701	5.1	-.4	253
196801	5.3	-.2	216
196901	3.9	-1.6	157
197001	5.5	.1	134
197101	4.7	-.8	230
197201	3.4	-2.0	154
197301	4.4	-1.1	142
197401	4.3	-1.2	116



JULAUGSEP

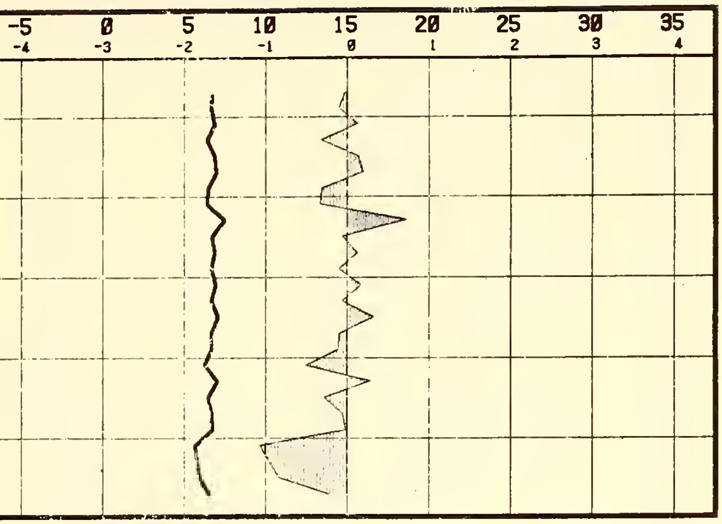
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	11.7	-1.5	29
195003	INSUF DATA		
195103	INSUF DATA		
195203	13.0	-.2	20
195303	13.1	-.1	42
195403	14.2	1.0	47
195503	11.7	-1.5	48
195603	13.3	.1	111
195703	15.9	2.7	73
195803	14.7	1.5	76
195903	13.3	.1	57
196003	13.0	-.2	97
196103	13.4	.2	135
196203	14.0	.7	213
196303	13.7	.4	230
196403	12.5	-.7	136
196503	11.7	-1.5	223
196603	12.4	-.8	245
196703	13.1	-.1	300
196803	13.7	.5	273
196903	12.1	-1.1	224
197003	11.6	-1.6	235
197103	11.1	-2.1	148
197203	12.2	-1.0	241
197303	11.1	-2.1	130
197403	12.8	-.4	179



MSQ 197-1

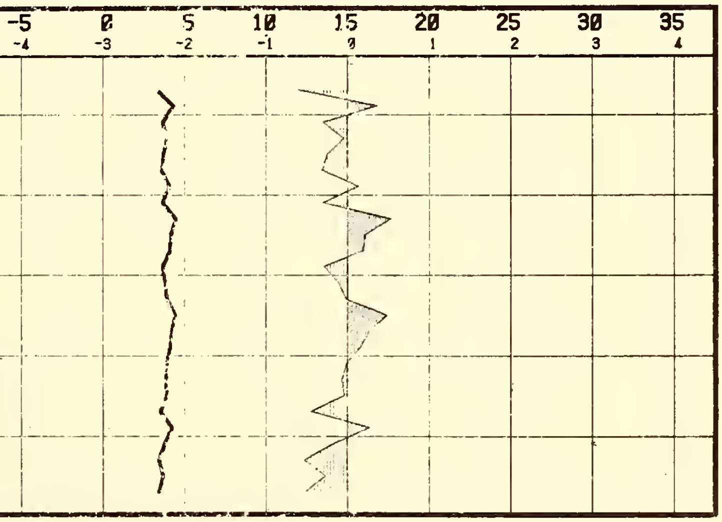
YEAR

YEAR	VALUE	ANOMALY	CBS
1948	INSUF DATA		
1949	6.7	-.0	272
1950	6.6	-.1	261
1951	6.9	.1	414
1952	6.4	-.3	358
1953	6.9	.1	425
1954	6.9	.2	504
1955	6.4	-.3	566
1956	6.4	-.3	712
1957	7.5	.7	799
1958	6.7	-.1	1152
1959	6.9	.1	879
1960	6.6	-.1	929
1961	6.9	.2	830
1962	6.7	-.1	1077
1963	7.1	.3	1317
1964	6.6	-.1	1527
1965	6.6	-.1	1545
1966	6.2	-.5	2218
1967	7.0	.3	3100
1968	6.5	-.3	3020
1969	6.7	-.1	1647
1970	6.7	-.0	1916
1971	5.7	-1.1	1359
1972	5.8	-1.0	1103
1973	5.9	-.8	1454
1974	6.5	-.2	1523



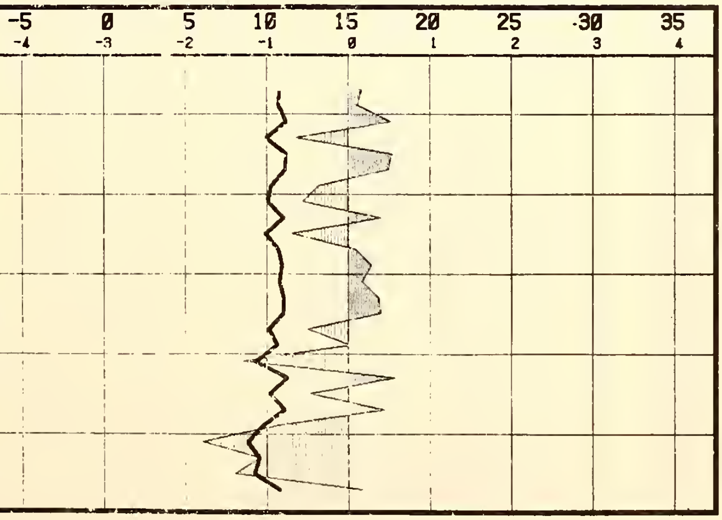
JANFEBMAR

QTR	VALUE	ANOMALY	CBS
194801	INSUF DATA		
194901	3.3	-.6	35
195001	4.3	.4	44
195101	3.6	-.3	57
195201	3.9	-.1	61
195301	3.7	-.3	73
195401	3.6	-.3	73
195501	4.1	.1	88
195601	3.6	-.3	117
195701	4.5	.5	80
195801	4.1	.2	113
195901	4.1	.2	275
196001	3.6	-.3	168
196101	3.8	-.1	169
196201	3.9	-.0	208
196301	4.4	.5	251
196401	4.2	.3	259
196501	4.1	.2	313
196601	3.9	-.0	479
196701	3.9	-.1	584
196801	3.9	-.0	502
196901	3.5	-.4	330
197001	4.2	.3	395
197101	3.8	-.2	293
197201	3.4	-.5	163
197301	3.7	-.3	290
197401	3.4	-.5	219



JULAUGSEP

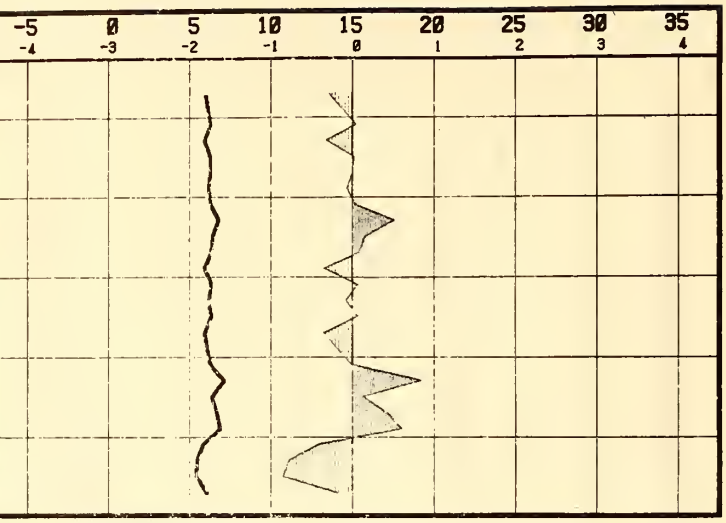
QTR	VALUE	ANOMALY	CBS
194803	INSUF DATA		
194903	10.8	.2	119
195003	10.7	.1	68
195103	11.1	.5	135
195203	10.0	-.6	106
195303	11.1	.5	173
195403	11.1	.5	203
195503	10.2	-.4	242
195603	10.1	-.6	258
195703	11.0	.4	327
195803	9.9	-.7	328
195903	10.7	.1	230
196003	10.9	.3	330
196103	10.8	.2	326
196203	11.0	.4	329
196303	11.0	.4	420
196403	10.1	-.5	450
196503	10.6	.0	433
196603	9.3	-1.3	672
196703	11.2	.6	834
196803	10.1	-.5	630
196903	11.1	.4	530
197003	9.7	-.9	592
197103	8.8	-1.8	352
197203	9.5	-1.1	323
197303	9.2	-1.4	392
197403	10.8	.2	420



MSQ 198-1

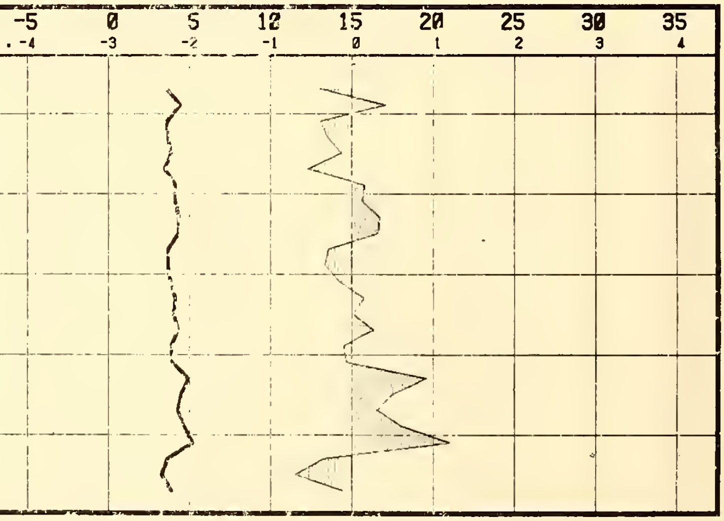
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	5.9	-.3	201
1950	6.1	-.1	188
1951	6.3	.0	367
1952	5.9	-.3	272
1953	6.3	.0	319
1954	6.2	.0	370
1955	6.2	-.1	371
1956	6.3	.0	636
1957	6.8	.5	778
1958	6.4	.2	762
1959	6.3	.1	878
1960	5.9	-.3	920
1961	6.3	.1	451
1962	6.2	-.1	413
1963	6.3	.1	422
1964	5.9	-.4	1737
1965	6.1	-.2	1730
1966	6.2	-.0	334
1967	7.1	.8	368
1968	6.4	.1	373
1969	6.7	.4	317
1970	6.8	.6	374
1971	5.8	-.4	516
1972	5.5	-.8	938
1973	5.4	-.9	1230
1974	6.1	-.2	1257



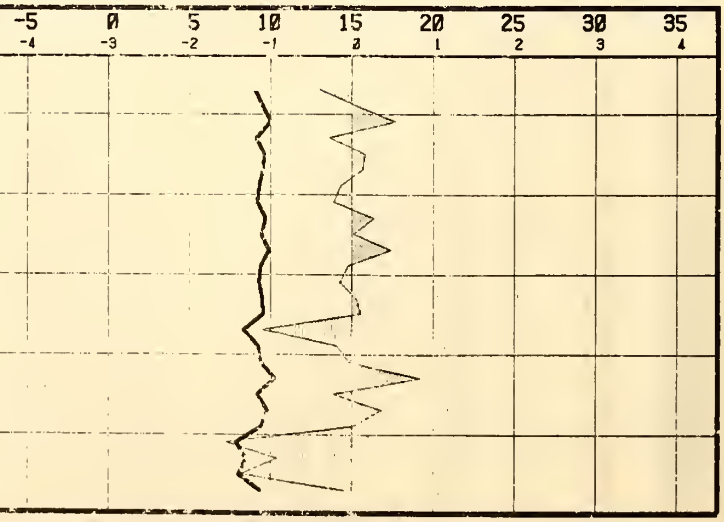
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	3.6	-.4	49
195001	4.4	.4	30
195101	3.6	-.4	52
195201	3.7	-.3	41
195301	3.8	-.1	42
195401	3.4	-.5	51
195501	4.1	.2	56
195601	4.1	.1	92
195701	4.3	.3	87
195801	4.3	.3	83
195901	3.7	-.3	132
196001	3.6	-.3	[illegible]
196101	3.8	-.1	123
196201	4.1	.1	[illegible]
196301	4.0	.0	129
196401	4.2	.3	270
196501	3.9	-.1	239
196601	3.9	-.1	101
196701	4.9	.9	63
196801	4.5	.5	81
196901	4.3	.3	51
197001	4.6	.6	81
197101	5.2	1.2	57
197201	3.6	-.3	175
197301	3.3	-.7	238
197401	3.8	-.1	2.7



JULAUGSEP

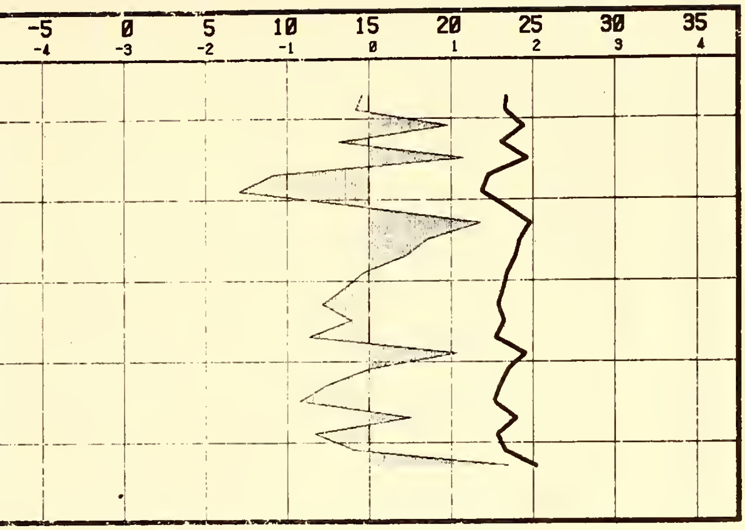
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	9.0	-.4	66
195003	9.4	.0	49
195103	9.9	.5	[illegible]
195203	9.1	-.3	75
195303	9.6	.2	124
195403	9.5	.1	150
195503	9.3	-.1	132
195603	9.2	-.2	251
195703	9.7	.3	270
195803	9.4	.0	[illegible]
195903	9.9	.5	338
196003	9.3	-.0	302
196103	9.2	-.2	93
196203	9.4	.1	130
196303	9.5	.1	140
196403	8.3	-1.1	611
196503	9.2	-.2	520
196603	9.4	-.0	[illegible]
196703	10.2	.8	[illegible]
196803	9.2	-.2	[illegible]
196903	9.8	.4	122
197003	9.4	.0	[illegible]
197103	7.9	-1.5	[illegible]
197203	8.5	-.9	[illegible]
197303	8.0	-1.4	352
197403	9.3	-.1	413



MSQ 308-1

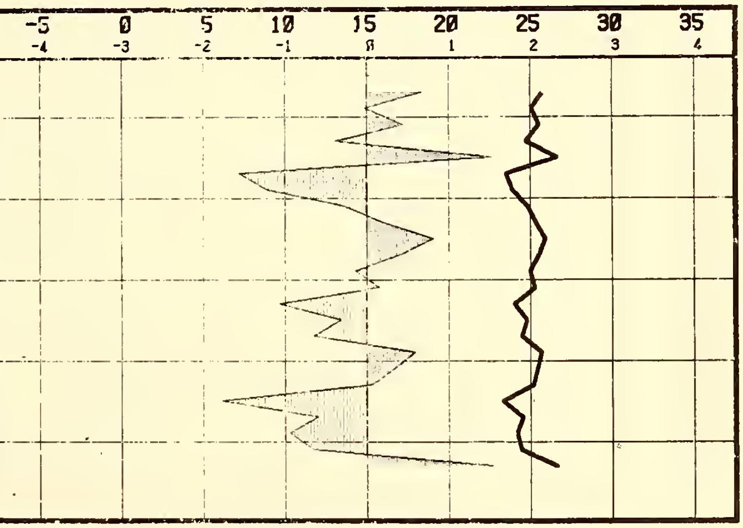
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	23.4	-.1	173
1950	23.3	-.2	158
1951	24.4	1.0	255
1952	23.1	-.4	305
1953	24.6	1.2	152
1954	22.3	-1.2	257
1955	21.9	-1.6	233
1956	23.4	-.1	312
1957	24.8	1.4	370
1958	24.2	.7	578
1959	23.9	.4	718
1960	23.4	-.1	755
1961	23.1	-.3	1002
1962	22.9	-.6	1059
1963	23.2	-.2	719
1964	22.7	-.7	630
1965	24.5	1.1	815
1966	23.4	.0	902
1967	22.9	-.5	646
1968	22.6	-.9	578
1969	24.0	.5	573
1970	22.8	-.7	525
1971	23.3	-.2	557
1972	25.1	1.7	522
1973	INSUF DATA		
1974	INSUF DATA		



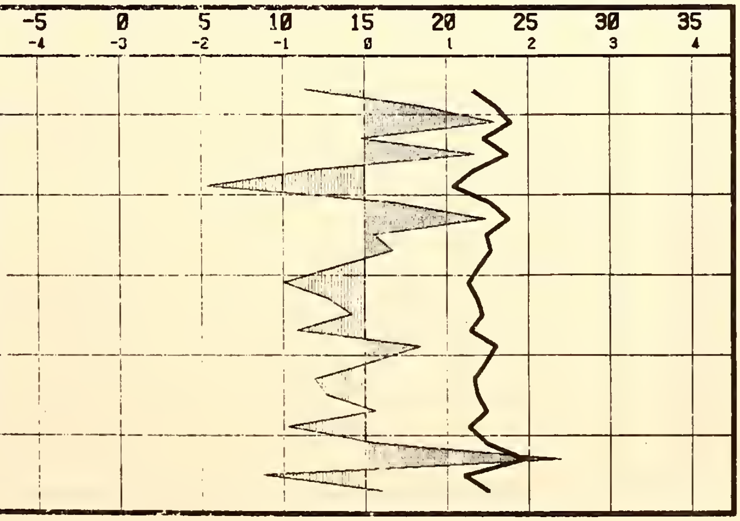
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	25.8	.7	60
195001	25.1	-.0	41
195101	25.5	.4	63
195201	24.7	-.4	78
195301	26.6	1.5	49
195401	23.5	-1.6	57
195501	23.9	-1.2	35
195601	24.8	-.3	63
195701	25.3	.2	61
195801	25.9	.8	114
195901	25.5	.4	267
196001	24.9	-.1	177
196101	25.2	.1	211
196201	24.0	-1.1	275
196301	24.8	-.3	154
196401	24.4	-.7	198
196501	25.7	.6	171
196601	25.4	.3	203
196701	25.1	.1	132
196801	23.3	-1.8	180
196901	24.5	-.6	150
197001	24.1	-.9	153
197101	24.4	-.7	144
197201	25.6	1.5	103
197301	INSUF DATA		
197401	25.0	-.1	23



JULAUGSEP

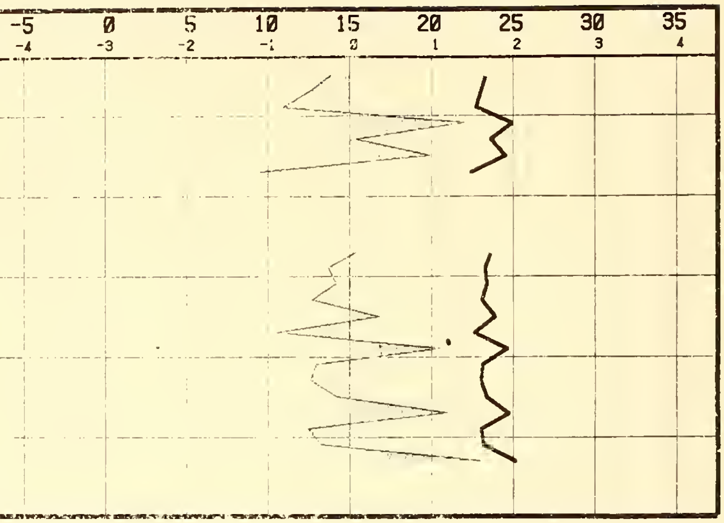
QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	21.6	-.7	47
195003	23.0	.7	40
195103	23.9	1.6	30
195203	22.3	-.0	75
195303	23.6	1.3	31
195403	21.6	-.7	47
195503	20.4	-1.9	33
195603	22.7	.4	62
195703	23.8	1.5	57
195803	22.4	.1	135
195903	22.6	.3	191
196003	22.0	-.3	231
196103	21.3	-1.0	269
196203	21.8	-.5	322
196303	22.1	-.2	156
196403	21.5	-.8	119
196503	23.0	.7	137
196603	22.4	.1	293
196703	21.7	-.6	159
196803	21.8	-.5	150
196903	22.4	.1	122
197003	21.4	-.9	110
197103	22.4	.1	108
197203	24.7	2.4	171
197303	21.0	-1.2	22
197403	22.5	.2	23



MSQ 309-1

YEAR

YEAR	VALUE	ANOMALY	OBS
1948	23.3	-.2	270
1949	23.0	-.5	238
1950	22.7	-.8	417
1951	24.9	1.4	232
1952	23.6	.1	337
1953	24.5	1.0	351
1954	22.4	-1.1	37[illegible]
1955	INSUF DATA		
1956	INSUF DATA		
1957	INSUF DATA		
1958	INSUF DATA		
1959	23.6	.1	470
1960	23.2	-.3	363
1961	23.3	-.2	493
1962	23.0	-.5	445
1963	23.9	.4	446
1964	22.6	-.9	[illegible]
1965	24.6	1.1	5[illegible]5
1966	23.1	-.4	5[illegible]9
1967	23.0	-.5	445
1968	23.3	-.2	5[illegible]5
1969	24.7	1.2	530
1970	23.0	-.5	[illegible]
1971	23.2	-.3	33[illegible]
1972	25.1	1.6	1[illegible]
1973	INSUF DATA		
1974	23.2	-.3	170



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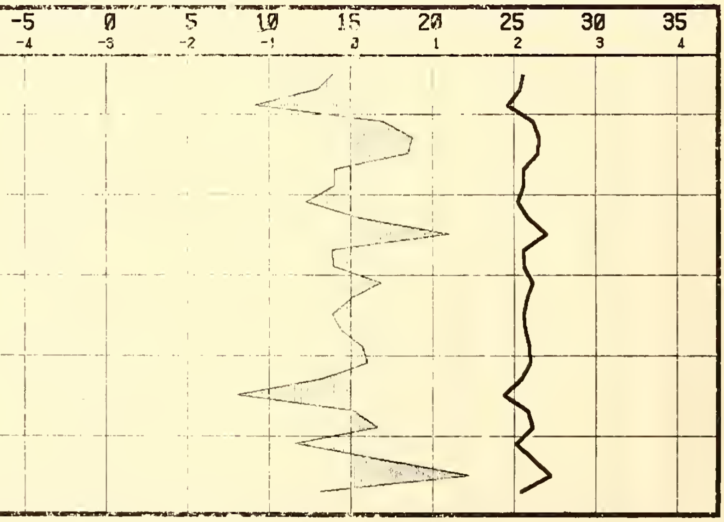
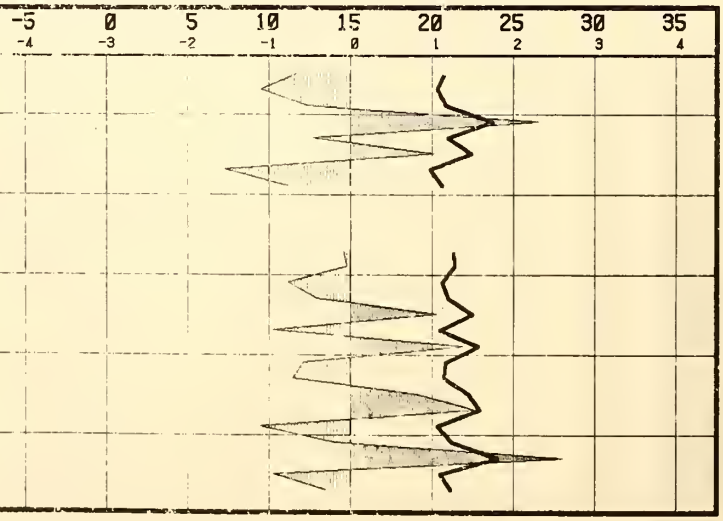
QTR	VALUE	ANOMALY	OBS
194801	25.6	-.2	53
194901	25.4	-.4	50
195001	24.6	-1.2	56
195101	26.2	.4	52
195201	26.5	.7	30
195301	26.5	.7	1[illegible]5
195401	25.6	-.2	72
195501	25.6	-.2	37
195601	25.2	-.5	[illegible]6
195701	25.9	.1	[illegible]7
195801	27.0	1.2	[illegible]7
195901	25.5	-.2	134
196001	25.5	-.2	133
196101	26.1	.4	142
196201	25.8	.0	1[illegible]1
196301	25.5	-.2	136
196401	25.6	-.1	300
196501	25.9	.1	132
196601	26.0	.2	135
196701	25.4	-.4	153
196801	24.4	-1.4	158
196901	25.8	.0	152
197001	26.1	.3	145
197101	25.1	-.7	147
197201	26.1	.4	30
197301	27.2	1.5	45
197401	25.4	-.4	42



JULAUGSEP

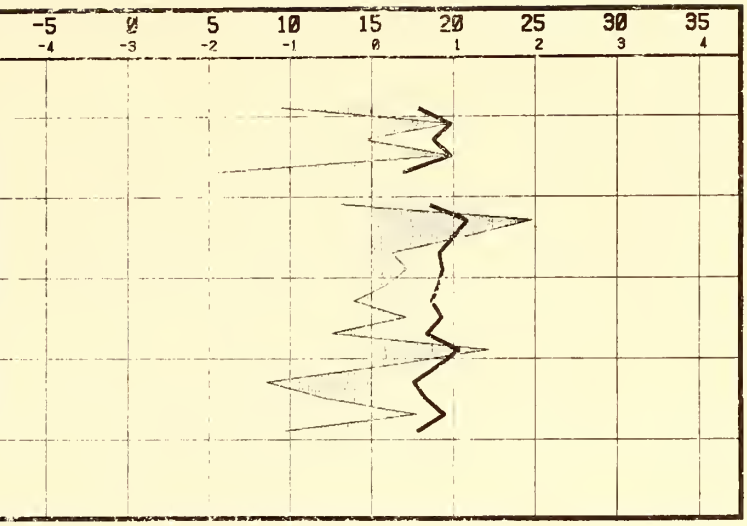
QTR	VALUE	ANOMALY	OBS
194803	20.7	-.6	54
194903	20.3	-1.1	57
195003	20.9	-.5	1[illegible]
195103	23.7	2.3	30
195203	20.9	-.5	36
195303	22.4	1.0	32
195403	19.9	-1.5	33
195503	20.6	-.8	34
195603	INSUF DATA		
195703	23.6	2.2	30
195803	INSUF DATA		
185903	21.3	-.1	[illegible]
196003	21.3	-.1	[illegible]9
186103	20.6	-.8	37
186203	21.0	-.4	39
198303	22.4	1.1	1[illegible]5
196403	20.4	-.9	1[illegible]4
196503	22.8	1.4	130
196603	20.8	-.6	1[illegible]5
196703	20.7	-.7	37
196803	22.2	.8	95
196903	22.9	1.5	132
197003	20.3	-1.1	1[illegible]
197103	21.2	-.2	33
197203	24.0	2.6	[illegible]
197303	20.4	-.9	26
197403	21.1	-.3	43



MSQ 343-2

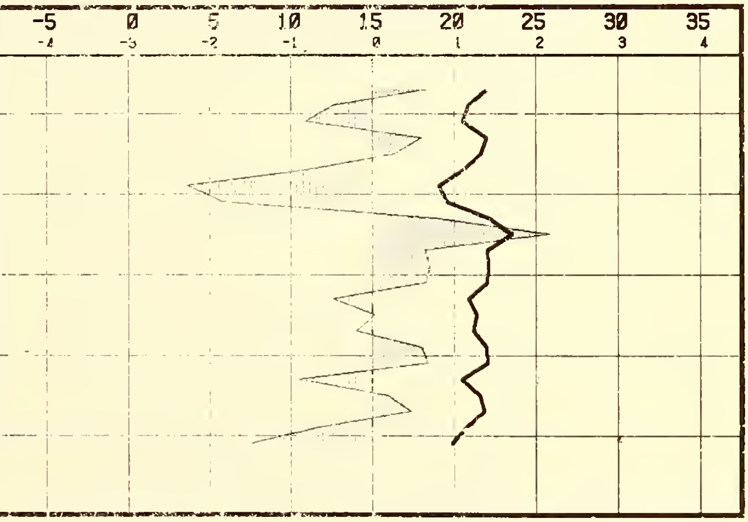
YEAR

YEAR	VALUE	ANOMALY	OBS
1948	INSUF DATA		
1949	INSUF DATA		
1950	17.7	-1.1	127
1951	19.8	1.0	252
1952	18.8	-.1	145
1953	19.8	1.0	132
1954	17.0	-1.9	138
1955	INSUF DATA		
1956	18.5	-.4	146
1957	20.8	2.0	234
1958	20.0	1.2	545
1959	19.1	.2	453
1960	19.3	.4	528
1961	19.0	.2	630
1962	18.6	-.2	717
1963	19.3	.4	[illegible]
1964	18.4	-.5	428
1965	20.3	1.4	[illegible]
1966	19.0	.2	414
1967	17.6	-1.3	248
1968	18.3	-.6	[illegible]
1969	19.4	.6	234
1970	17.8	-1.1	371
1971	INSUF DATA		
1972	INSUF DATA		
1973	INSUF DATA		
1974	INSUF DATA		



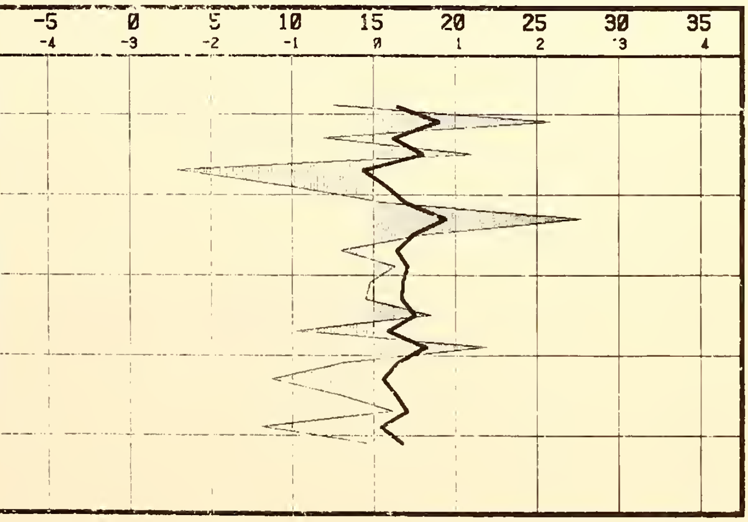
JANFEBMAR

QTR	VALUE	ANOMALY	OBS
194801	INSUF DATA		
194901	22.0	.7	39
195001	20.9	-.5	[illegible]
195101	20.5	-.8	[illegible]
195201	21.9	.6	[illegible]
195301	21.6	.3	37
195401	20.5	-.8	56
195501	19.1	-2.3	[illegible]
195601	19.5	-1.8	[illegible]
195701	22.1	.8	[illegible]
195801	23.5	2.2	[illegible]
195901	22.0	.6	[illegible]
196001	22.0	.7	145
196101	22.0	.7	[illegible]
196201	20.9	-.5	227
196301	21.4	.0	[illegible]
196401	21.1	-.2	144
196501	21.9	.6	107
196601	22.0	.7	[illegible]
196701	20.4	-.9	70
196801	21.5	.2	64
196901	21.8	.5	[illegible]
197001	20.7	-.6	33
197101	19.9	-1.5	103
197201	INSUF DATA		
197301	INSUF DATA		
197401	20.7	-.7	25



JULAUGSEP

QTR	VALUE	ANOMALY	OBS
194803	INSUF DATA		
194903	INSUF DATA		
195003	16.3	-.5	39
195103	18.9	2.2	[illegible]
195203	16.2	-.6	25
195303	18.0	1.2	34
195403	14.4	-2.4	42
195503	15.7	-1.1	[illegible]
195603	16.9	.1	41
195703	19.3	2.5	[illegible]
195803	17.4	.6	[illegible]
195903	16.4	-.4	[illegible]
196003	17.0	.3	[illegible]
196103	16.7	-.0	165
196203	16.7	-.1	192
196303	17.5	.7	[illegible]
196403	15.8	-.9	93
196503	18.2	1.4	[illegible]
196603	16.4	-.4	124
196703	15.5	-1.3	[illegible]
196803	16.4	-.4	[illegible]
196903	17.0	.2	[illegible]
197003	15.4	-1.4	[illegible]
197103	16.7	-.1	[illegible]
197203	INSUF DATA		
197303	INSUF DATA		
197403	16.8	.0	21



SEA SURFACE TEMPERATURE CONDITIONS IN THE NORTH PACIFIC OCEAN - 1974*

by

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Southwest Fisheries Center
La Jolla, California 92038

*Submitted to "Status of the Environment Report" for 1974.

June 1975

Southwest Fisheries Center
Administrative Report No. LJ-75-64

SEA SURFACE TEMPERATURE CONDITIONS IN THE

NORTH PACIFIC OCEAN - 1974

L.E. Eber

Water temperatures in the surface layer of the North Pacific did not exhibit any wide-spread, large departures from normal in 1974. Considering only the area north of latitude 20°N, the year started out predominently warmer than normal. Reduced seasonal warming in spring and early summer brought on predominently cooler-than-normal water temperatures in the surface layers and this condition prevailed, although in diminishing degree, during the remainder of the year.

The pattern transformations in the anomalous sea surface temperature field are shown in Figures 1-5. These patterns are based on published deviations of sea temperature from 1948-67 monthly means.[1]

In January and February (Figure 1), negative deviations were confined to a broad zone averaging about 1600 km wide, along the coast of North America, and to a region of similar area southwest of Japan. During the next few months (Figures 2 and 3) these areas of negative deviations expanded and spread toward mid-ocean, particularly in the latitudinal zone 35° to 45°N, and north of latitude 50°N. In July and August (Figure 4), the two areas of negative anomaly merged between 35° and 45°N and contained maxima exceeding 2°F (1.1°C) at 145° to 160°W and 4°F (2.2°C) at 165° to 170°E. In the same period, however, the negative anomaly withdrew from the region south of the Aleutian Islands and the western Gulf of Alaska. Positive deviations from latitude 25° to 35°N spread eastward toward the U.S. west coast.

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[1] James A. Renner. 1974. Fishing Information, Nos. 1-12.

Anomalous warming occurred in the eastern North Pacific during September, causing an abrupt transition from negative to positive anomalies at mid-latitude between 130° and 145°W. The resulting pattern of negative deviations extending from the western Pacific to 145°W, between latitudes 30° to 40°N, partially surrounded by positive deviations to the north, east, and south, persisted throughout the remainder of the year (Figure 5).

Sea surface temperatures in the eastern North Pacific, east of 135°W, are monitored on a semi-monthly basis at the Southwest Fisheries Center, in connection with investigations of the albacore tuna fishery. The albacore fishing season begins in late May or early June, at the beginning of the warming season, and runs through October. The effects of seasonal warming on the sea surface temperature field is portrayed in Figure 6 by the progression of the 60°F (15.6°C) isotherm from May to September.[2] In 1974, there was a gradual northward shift of the pattern from May 1-15 to July 1-15, followed by a rapid displacement to the August 1-15 position. In each of these periods, however, the 60°F isotherm was, for the most part, south of its respective long-term mean position, reflecting the anomalously cool condition generally prevailing along the coast. The continued northward shift from August 1-15 to September 1-15 was substantially greater than normal and resulted in the change from negative to positive anomaly noted in Figures 4 and 5.

The seasonal migration of the albacore into the eastern North Pacific fishing grounds and their subsequent movements during the season bears a similarity to the season progression of the sea surface temperature pattern.

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[2] Taken from 15-day sea surface temperature charts published as the Fishing Information Supplement, Southwest Fisheries Center, NMFS, NOAA.

Based on catch statistics,[3] the albacore in 1974 approached the coast from the central Pacific in the neighborhood of latitude 35°N during June, turned northward and spread out in a zone roughly 300 miles wide from latitude 35° to 52°N.

Most of the catches were made in waters with temperatures between 58° and 64°F (14.4° to 17.8°C), however, the northward movements of the fish during the first half of July, as inferred from the catches, preceeded the northward advance of the 58° isotherm. Also, catches were made throughout the season in 56°F (13.3°C) upwelled water along northern California and southern Oregon.

[3] Catch statistics based on logbook records and interviews with fishermen were compiled jointly by National Marine Fisheries Service, Washington Department of Fisheries, Fish Commission of Oregon, and California Department of Fish and Game.

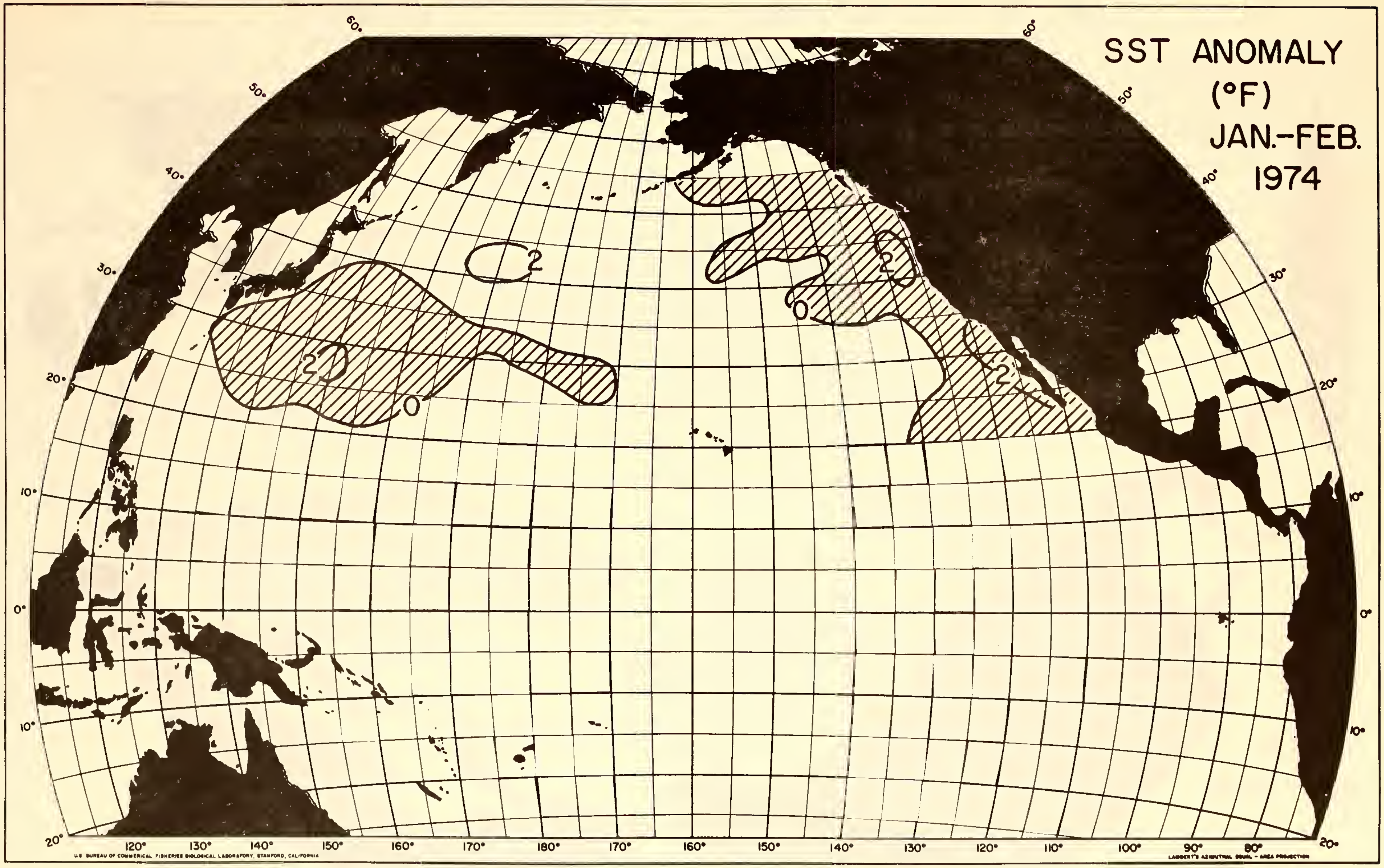

Figure 5.1. Average sea surface temperature anomaly (in °F) in the Pacific Ocean north of latitude 20°N for January and February 1974. Hatched areas indicate below normal temperatures.

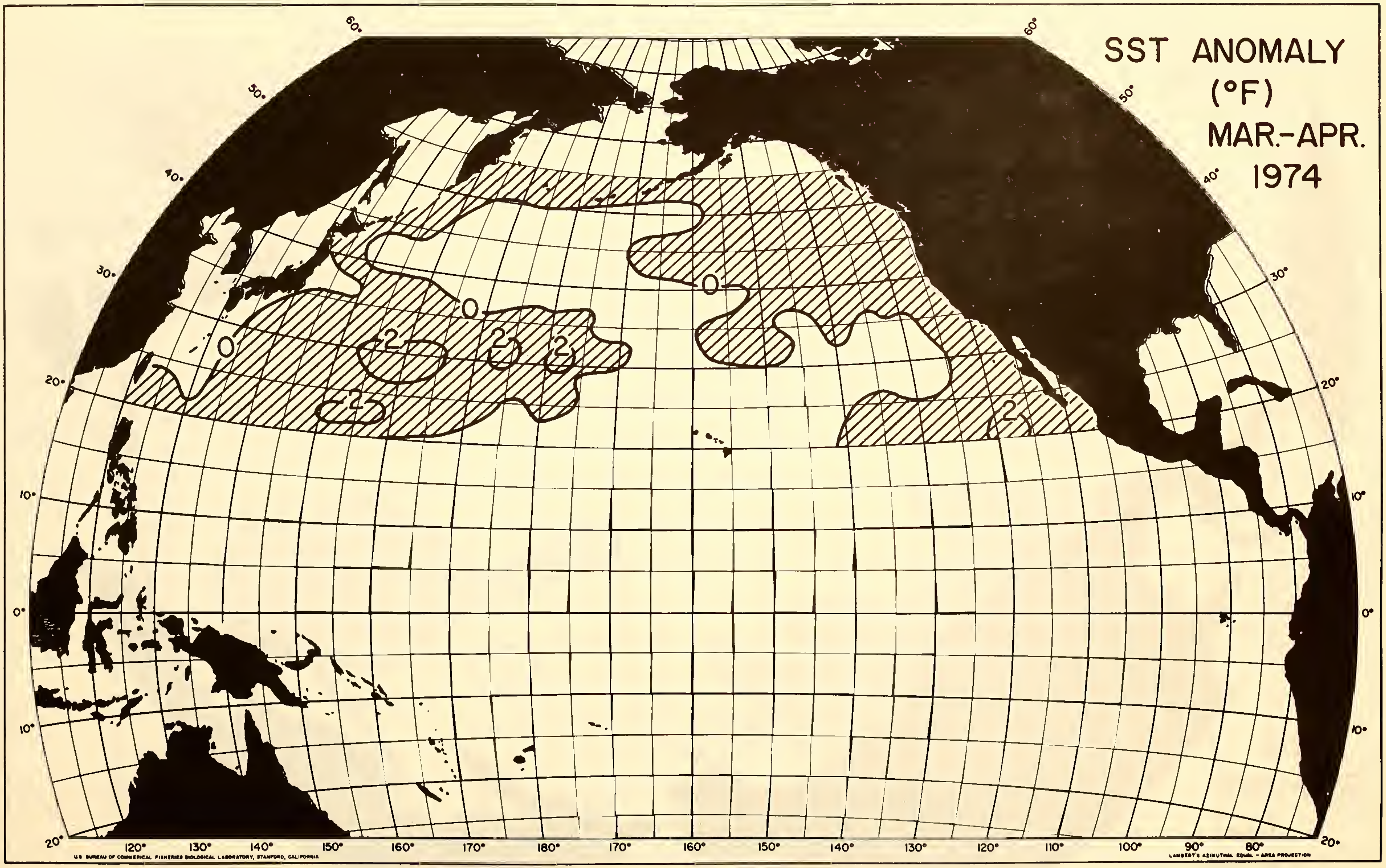

Figure 5.2. Average sea surface temperature anomaly (in °F) in the Pacific Ocean north of latitude 20°N for March and April 1974. Hatched areas indicate below normal temperatures.

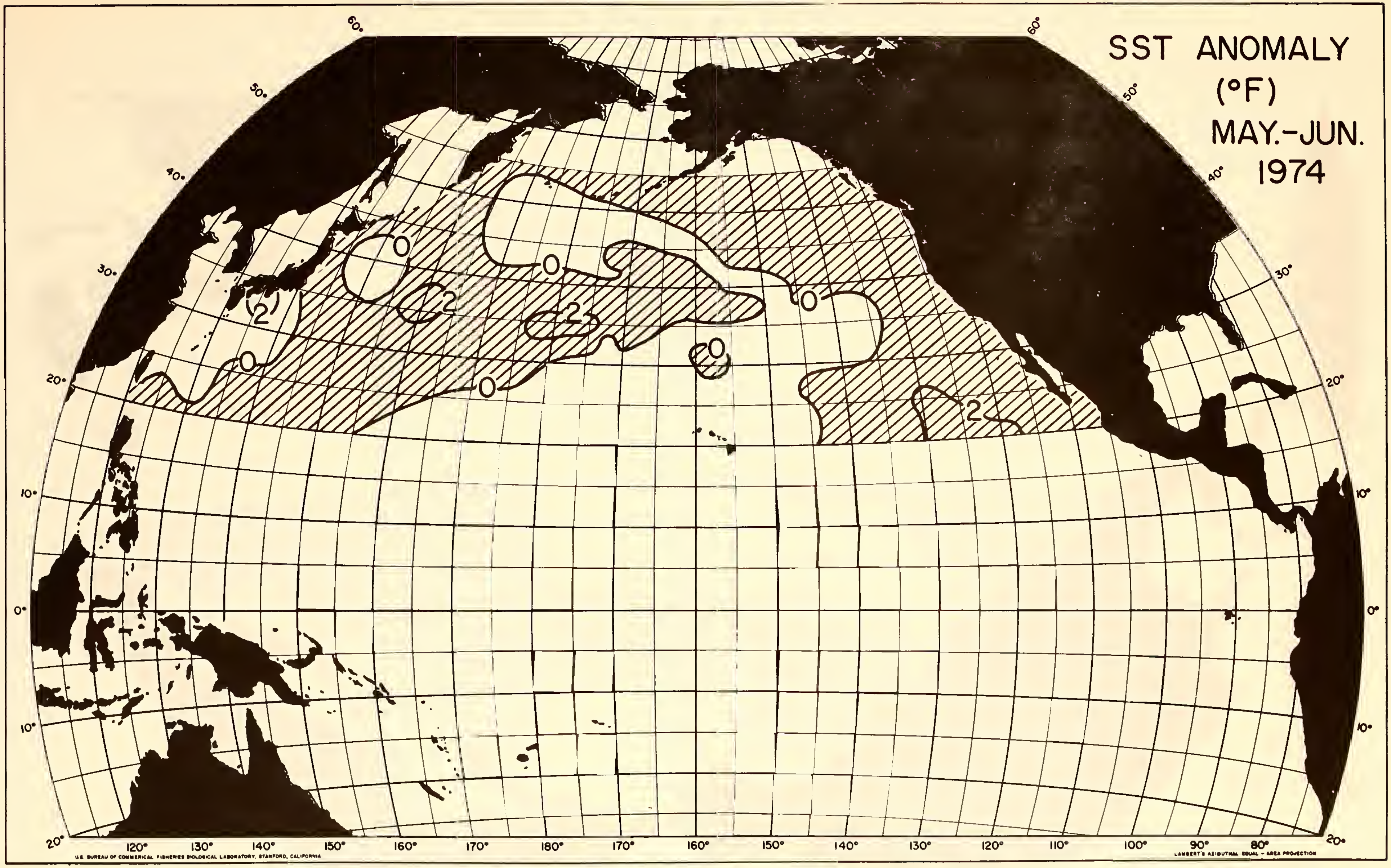

Figure 5.3. Average sea surface temperature anomaly (in °F) in the Pacific Ocean north of latitude 20°N for May and June 1974. Hatched areas indicate below normal temperatures.

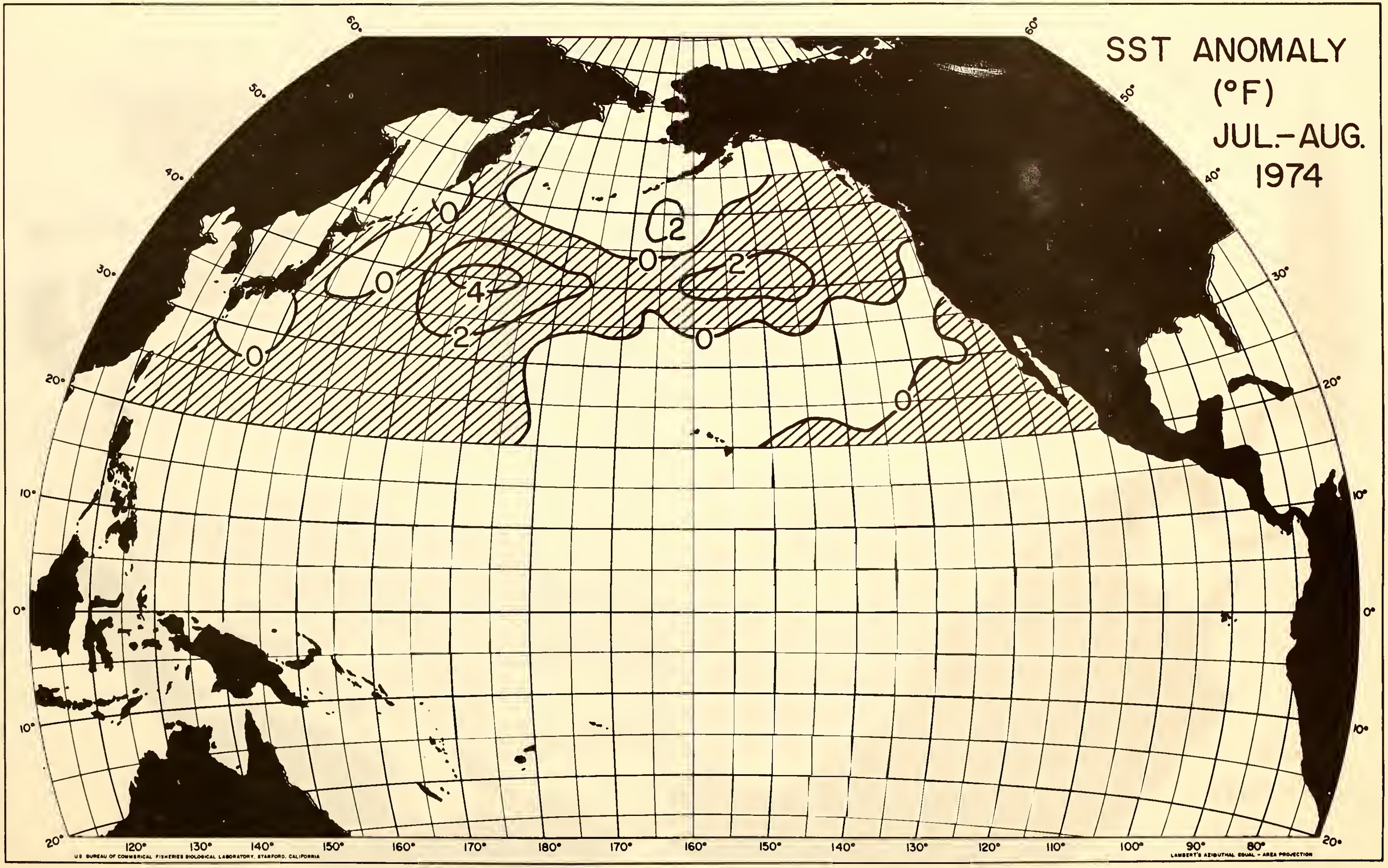

Figure 5.4. Average sea surface temperature anomaly (in °F) in the Pacific Ocean north of latitude 20°N for July and August 1974. Hatched areas indicate below normal temperatures.

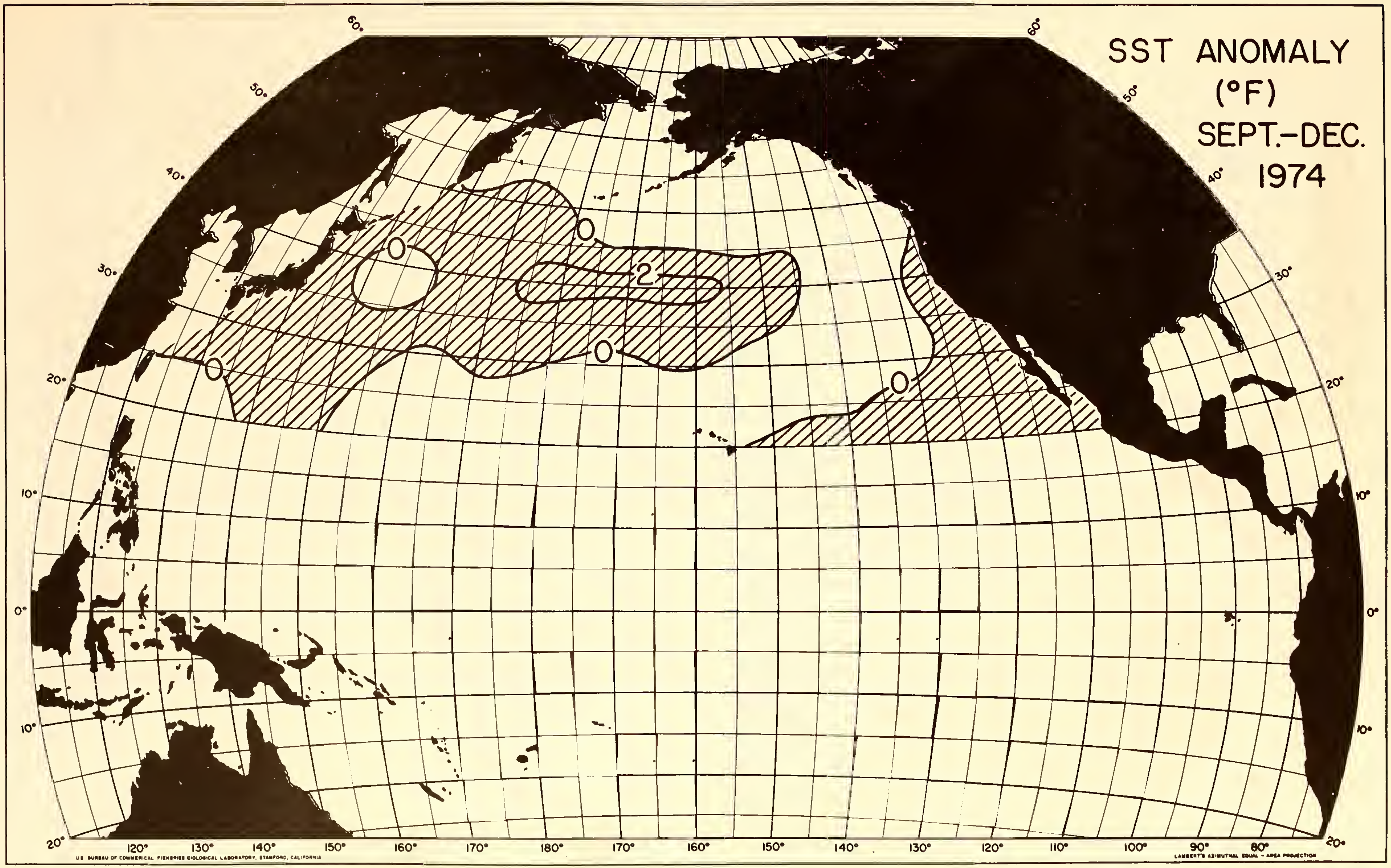

Figure 5.5. Average sea surface temperature anomaly (in °F) in the Pacific Ocean north of latitude 20°N for September through December 1974. Hatched areas indicate below normal temperatures.

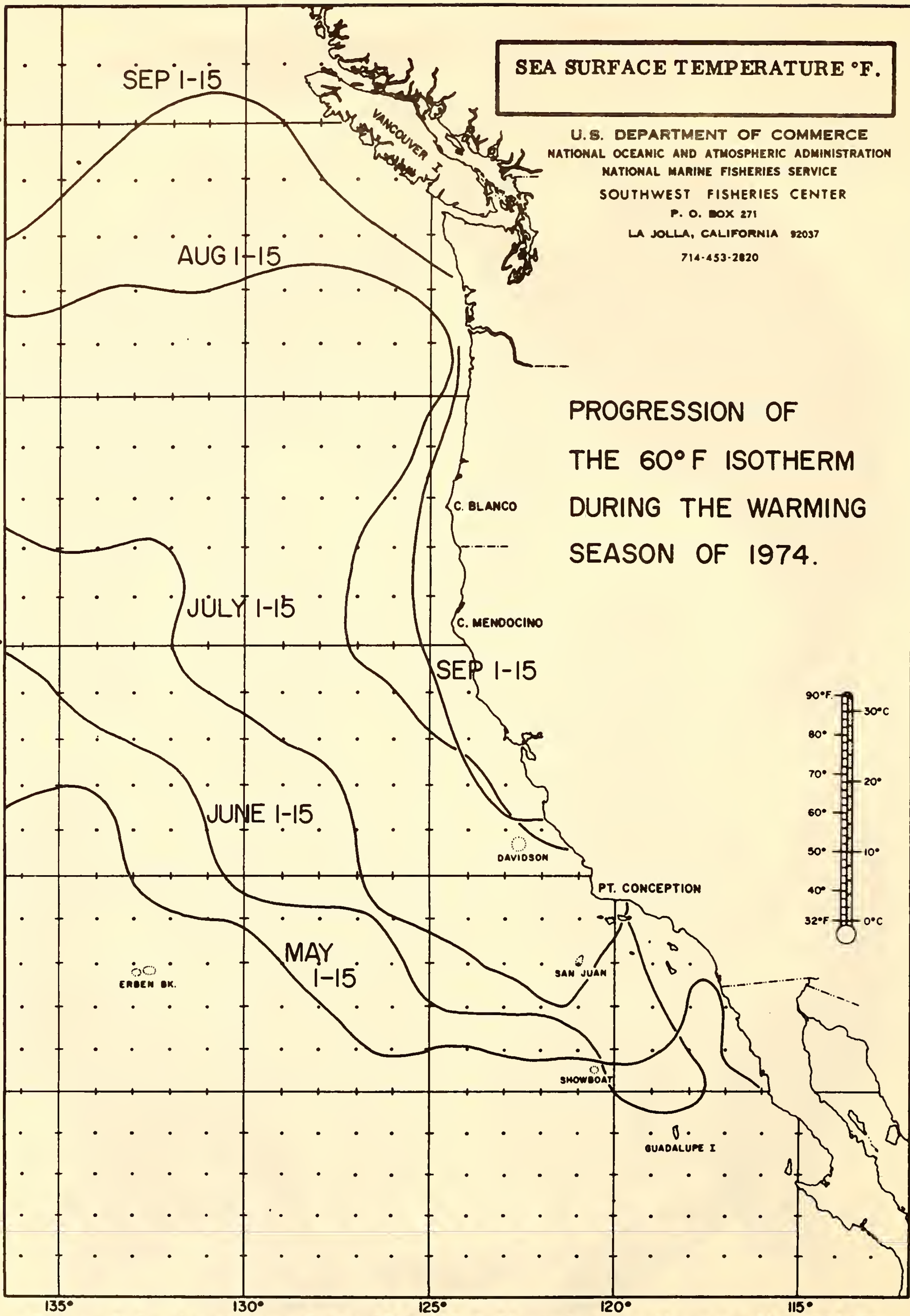

Figure 5.6. Locations of the 60°F (15.6°C) surface isotherm in the eastern north Pacific for the first 15 days of May through September 1974, respectively.

CHANGES IN THE TRANSITION ZONE AND HEAT STORAGE IN 1974 BETWEEN HAWAII AND CALIFORNIA

J.F.T. Saur*

INTRODUCTION

In 1974 the oceanic conditions in the northeast Pacific Ocean were significantly changed from those in the two previous years, according to data obtained from a National Marine Fisheries Service (NMFS) project for ocean monitoring between Hawaii and the U.S. West Coast. One of several objectives of this monitoring is to detect seasonal and non-seasonal movements and changes in character of the Transition Zone which is found between the modified subarctic waters of the California Current and the subtropical or Eastern North Pacific central waters centered northeast of Hawaii, Figure 6.1. Laurs and Lynn (1975) have shown that this zone and its associated oceanic fronts influence the distribution and apparent abundance of albacore tuna during their early season migration toward the U.S. west coast fishery (see Section 8).

Throughout most of 1974 the Transition Zone was diffuse and its edges poorly defined as compared to 1973. As the year ended a strong temperature and surface salinity front was forming at its boundary with the California Current, whereas in 1973 the stronger salinity front had been on the subtropical side of the Transition Zone.

GENERAL OCEANIC FEATURES

Between the California coast and Hawaii we can identify three oceanic regions: (1) a California Current region, (2) a Transition Zone, and (3) a subtropic region, Figure 6.1. The waters in the California Current

*Scripps Institution of Oceanography, La Jolla, CA. (Affiliated with NMFS Southwest Fisheries Center, La Jolla, through 1974).

originate as cool and low salinity subarctic waters but undergo continuous modification (warming and increasing salinity) in their southward movement along the coast. These generally extend some 500 to 600 nautical miles out from the coast on the Honolulu - San Francisco route.

The subtropical waters, or Eastern North Pacific Central (ENP) waters, are warm, high salinity waters. They occupy about one-half of the route, i.e. from Hawaii for 1,000 miles northeastward to the neighborhood of 31° N latitude and 139° W longitude.

Between these two principle water masses lies a Transition Zone (Roden, 1971). Its temperatures and salinities are characteristic of a mixture of the two primary water masses (Christensen and Lee, 1965), and the boundaries are often marked by sharp horizontal salinity gradients (Roden, 1971). In early spring the vertical temperature profiles in the Transition Zone often exhibit complex minimum-maximum structures at depths of 50-150 meters below the surface.

These features between Hawaii and California are extensions of the Transition Zone and its associated subtropical front and subarctic front which occur between Hawaii and Alaska. Roden (1970) has shown that at longitude 158° W and 178° W the fronts are oriented east-west and the Transition Zone lies between 32° N and 42° N. Between Hawaii and California the features are oriented WNW-ESE or NW-SE due to the currents turning clockwise around the central gyre of the North Pacific Ocean.

OBSERVATIONS

Observations for the ocean monitoring are made from merchant vessels or "ships of opportunity" (Saur and Stevens, 1972). Underway observations of subsurface temperatures to depths of 500 meters are made by the ship's mates using an XBT (expendable bathythermograph) system. Engineers draw water samples from the sea water intake system for determination of "surface" salinity. With observations every 4 hours the distance between observations varies from 65 nautical miles (120 km) to 90 nautical miles (165 km) depending upon vessel speed.

Monitoring is now done regularly on 3 routes in the NE Pacific, Figure 6.1. It began with a pilot project on the San Francisco - Hawaii route in June 1966 at the rate of 15-18 sections per year. During the past two years the monitoring has been expanded and intensified. Observations started on the Los Angeles - Honolulu route in October 1973 and on the Seattle - Honolulu route in April 1974 at the rate of 15-20 sections per year. On the San Francisco route the number of sections was increased to 27 (650 observations) in 1973 and the route intensively sampled in 1974 with 52 sections (1420 observations). Selected sections, along with a narrative interpretation (Saur, 1972-75) are published monthly in Fishing Information, a NOAA/NMFS publication compiled and distributed monthly by the Southwest Fisheries Center, La Jolla, California. Figure 6.2 is an example of the graphical presentation of the data for March, 1974, on the Honolulu - San Francisco route. This paper will focus its attention on oceanic conditions observed along the San Francisco route because of the intensified sampling in recent years.

It should be noted that the "monitoring" permits a description of meso-scale features throughout each year to supplement the knowledge gained from highly detailed sections by oceanographic research vessels (Laurs and Lynn, 1975; Roden, 1970 and 1971) at only one time in a given year.

OCEANIC CONDITIONS IN 1974

For our purposes the oceanic conditions in 1974 can best be described by noting the shift from those which were found in 1973. (Conditions in 1972 and 1973 were quite similar.) To summarize these I will use the surface salinity and temperature observations and the heat content derived from the subsurface temperature data.

Figures 6.3 and 6.4 show the distribution of surface salinity and temperature, respectively, along the Honolulu - San Francisco route for 1973 and 1974. Whereas, the temperature patterns exhibit large seasonal cycles, the salinity patterns do not.

Surface Salinity

Surface salinities of greater than 35 °/₀₀ are typical of the ENP central waters. Salinities below 33.5 °/₀₀ are typical of California Current waters and salinities below 33 °/₀₀ persist most of the year in the core of the current. The Transition Zone on the San Francisco route has surface salinities generally between 33.7 °/₀₀ and 34.7 °/₀₀.

Several changes from 1973 may be noted in the 1974 salinity pattern. (1) In 1974 as opposed to 1973 there is a large amount of water with salinities below 35 °/₀₀ at the Hawaii end of the section. These appeared at the end of 1973 and persisted throughout 1974. (2) The salinity reached 35.5 °/₀₀ on only one observation in 1973 but values this high were observed for several months in the latter half of 1974. The position of the maximum salinity also shifted towards the west coast by 100-200 miles. (3) In the eastern half of the section the 35 °/₀₀ and 34 °/₀₀ isohalines in 1974 shifted somewhat eastward.

These changes in salinity patterns suggest that in 1974 the center of the ENP waters moved northward about 2° latitude and protruded eastward, and lower salinity waters of the California Current Extension (Seckel, 1962) and equatorial regions moved into the Hawaiian Island area. This movement coincided with stronger and more persistent trade winds in 20-25° N and 25-30° N latitude belts east of Hawaii.

A change in the strength of the salinity boundary of the Transition Zone occurred with the above described shift in salinity pattern. This could be seen in the horizontal profiles of surface salinity. Figure 6.5 shows salinity for March in each of four years 1972 through 1975. March profiles, as a rule, are typical of the predominant pattern from the previous winter through the following spring and summer.

In March 1973 two steep gradients, or fronts, in the salinity profiles occurred, one near 140° W and another near 133° W. In between these fronts the salinities were near 34 °/₀₀. The Transition Zone appeared to be a separate distinct region of relatively uniform salinity and bounded by two salinity fronts. The front on the subtropical, or Hawaii, side was the stronger of the two.

In March 1974 there were no distinct gradients to bound a Transition Zone. Throughout spring, summer and fall the salinities, and also temperature, showed the transition from California Current waters to ENP central waters was broad and diffuse. On its early season albacore scouting cruises in June-July 1974, the research vessel, David Starr Jordan, also found only weak fronts and a diffuse Transition Zone as opposed to two sharp boundaries in 1973.[1]

About October 1974 a steep salinity gradient began to appear near 130°-132° W and by March 1975 sharply defined the outer boundary of the low salinity California Current waters, Figure 6.5.

Surface Temperature and Heat Storage

Changes in temperature and heat storage occurred in conjunction with the shift in salinity patterns just described. A greater range of surface temperatures occurred in the annual pattern in 1974 than 1973, Figure 6.4. A temperature minimum of 11.8°C occurred at the San Francisco end of the section in February of 1973. The maximum off Hawaii was 25.9°C in September for a total range of 14°C. In 1974, however, the February minimum was 11° and the September maximum was 27°C for a total range of 16°C. The contrast between temperatures near San Francisco and those near Hawaii, even on a month-by-month basis, Figure 6.4, were 2°C greater in 1974 than in 1973.

The temperature changes were not confined to the surface, but also penetrated below the surface. This is shown by the March and September heat content (relative to 0°C) of the upper 100 meters in 1973 and 1974, Figure 6.6. Except near the California coast the heat content in the 0-100 meter layer was generally greater in both seasons in 1974 than in

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[1]Personal communication, R. J. Lynn, Scientist-in-charge.

1973. The excess was about 10 kilogram-calories. This amount raises the average temperature of a 100 meter column of water by 1°C. This indicates that the warm pool (in surface temperature) in the subtropics noted in 1974 by Namias and Dickson (see Section 3) and by Eber (see Section 5) extended well below the surface, at least, in the region northeast of Hawaii.

In the western half of the section where the 1974 excess was greatest, the warming from March to September was about the same in each year. The difference between years occurred because the cooling in the winter of 1973-74 did not offset the warming that had taken place in the summer of 1973. The cause of this has not yet been identified.

The only significant cooling from 1973 to 1974 occurred in the few hundred miles closest to the California coast. In contrast to when warming occurred in other areas, the coastal cooling occurred mainly because of March to September differences between years. The increase of heat content during these months in 1974 was small compared to that in 1973. This indicates that the California Current became confined to a narrower band closer to the coast by September 1974 in comparison with September 1973. Greater upwelling and a stronger California Current advecting more heat out of the region would account for the smaller summer rise in heat content. This confirms stronger upwelling around 36° N latitude predicted by Bakun's upwelling index (see Section 12).

SUMMARY

In 1974 the center of the warm high salinity Eastern North Pacific Central water shifted northward by about 2° latitude (from about 28° N to 30° N) and protruded northeastward (near 32° N, 138° W) toward the California coast. This movement was accompanied by a change in the character of the Transition Zone. In 1973 the zone had been well defined by sharp boundaries with the California Current waters and with the subtropical Eastern North Pacific central waters. The latter boundary had the stronger surface salinity front. In most of 1974 the fronts were weak so that the Transition Zone was diffuse and its limits not clearly identified. Near the end of 1974 the boundary between the subtropical waters and the Transition Zone remained indistinct. However, a strong temperature and surface salinity front formed at the boundary between the cool low salinity waters of the California Current and the Transition Zone.

The contrast in temperature and heat content between the subtropical waters and coastal waters of California increased from 1973 to 1974. The year 1974 ended with a larger pool of heat in the subtropical waters. This contrasted with cooler conditions in a 400-500 nautical mile band along the California coast.

The difference in distribution of heat could be of importance to air-sea interaction and feedback of energy from the ocean to the atmosphere. On the other hand the environmental features which could be of importance to fisheries were the change in character of the Transition Zone and the shift of the stronger frontal boundary to the California side of the zone.

ACKNOWLEDGMENTS

A monitoring program of this nature involves many people and activities. Cooperation of companies and the mates and engineers of the following ships is greatly appreciated: *SS Monterey* and *SS Mariposa*, Pacific Far East Line; *Hawaiian Enterprise*, *Californian*, and *Hawaiian Queen*, Matson Navigation Company; and *Chevron Mississippi* and *Chevron California*, Chevron Shipping Company. Robert Melrose, Marine Technician, NMFS Pacific Environmental Group, Tiburon, CA (succeeded by Brian Jarvis in November 1974) performed the difficult tasks of maintaining equipment and servicing ships. Dr. Douglas R. McLain supervised the initial processing of observations at NMFS Pacific Environmental Group, Monterey, using the computer facilities of the Fleet Numerical Weather Central (FNWC), Monterey. FNWC also furnished the XBT probes for the observations - a major cost item of the project. Hilary Hogan, NMFS Southwest Fisheries Center, La Jolla, supplied indispensable assistance to me in data handling and analyses. The project was supported by National Science Foundation (Office of IDOE) grant AG-256, Office of Naval Research Gov, Order NAour-9-74 to the National Marine Fisheries Service, and ONR contract N00014-75-C-0260 with Scripps Institution of Oceanography (NORPAX program).

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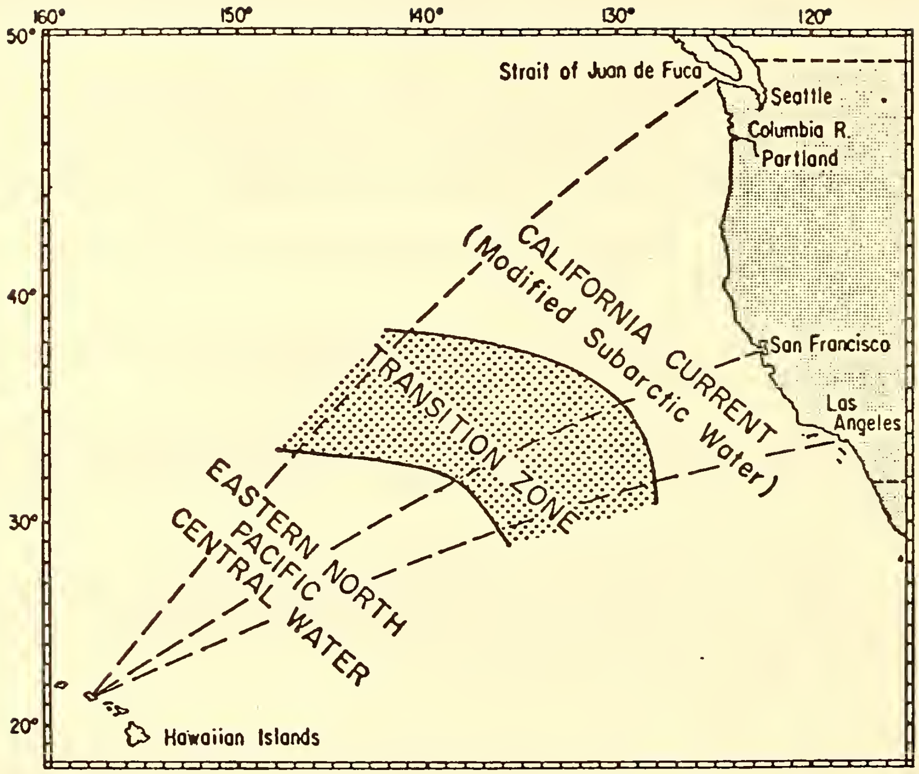

Figure 6.1. Location of water masses and Transition Zone in late July and early August 1974. (Adapted from FISHING INFORMATION, August 1974, No. 8.) Ocean monitoring by merchant ships was conducted in 1974 along the three routes shown by dashed lines.

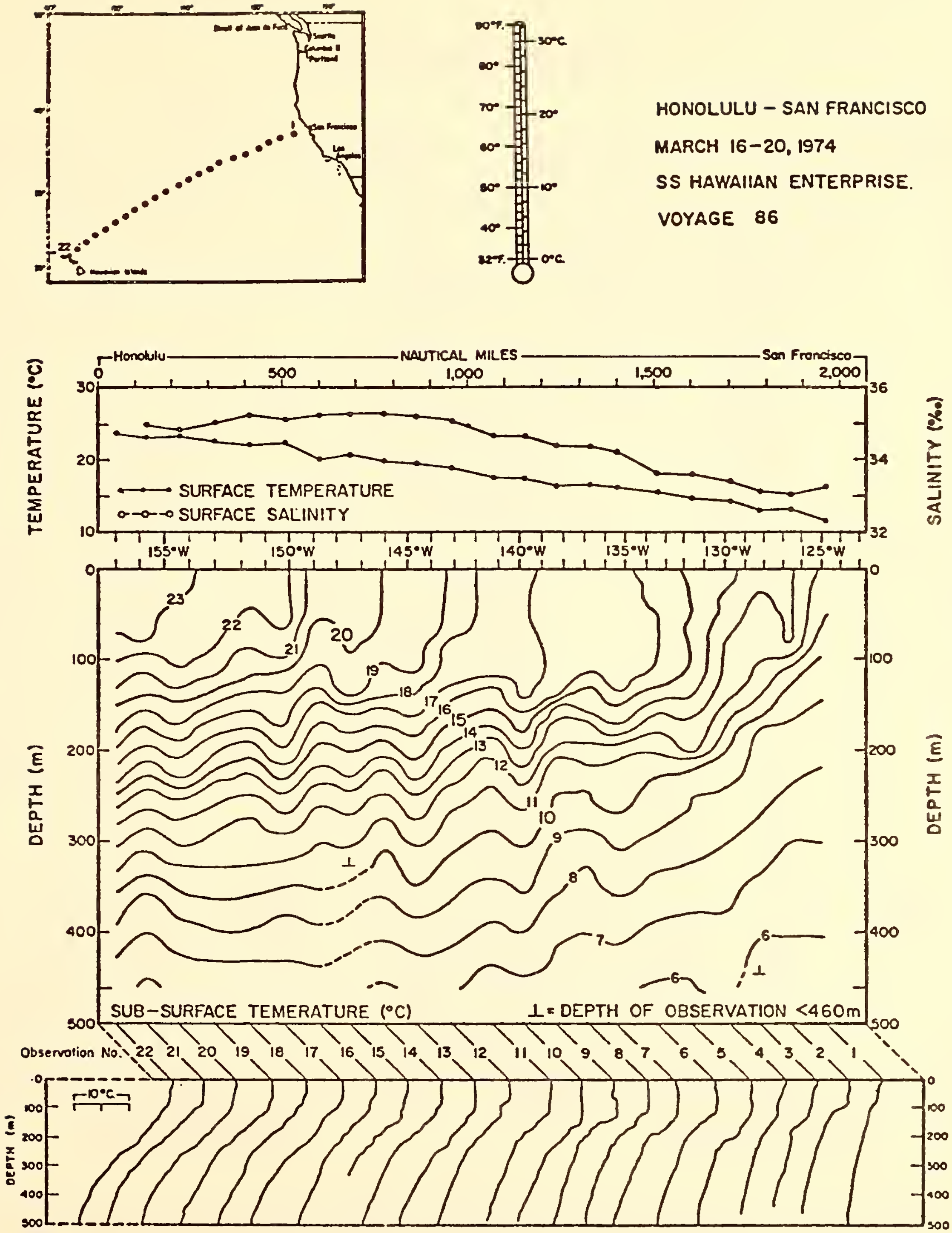

Figure 6.2. Surface temperature and salinity and subsurface temperature structure, Honolulu - San Francisco ship route, March, 1974. Selected sections for the three routes shown in Figure 6.1 were published in monthly issues of FISHING INFORMATION, distributed by the Southwest Fisheries Center, La Jolla.

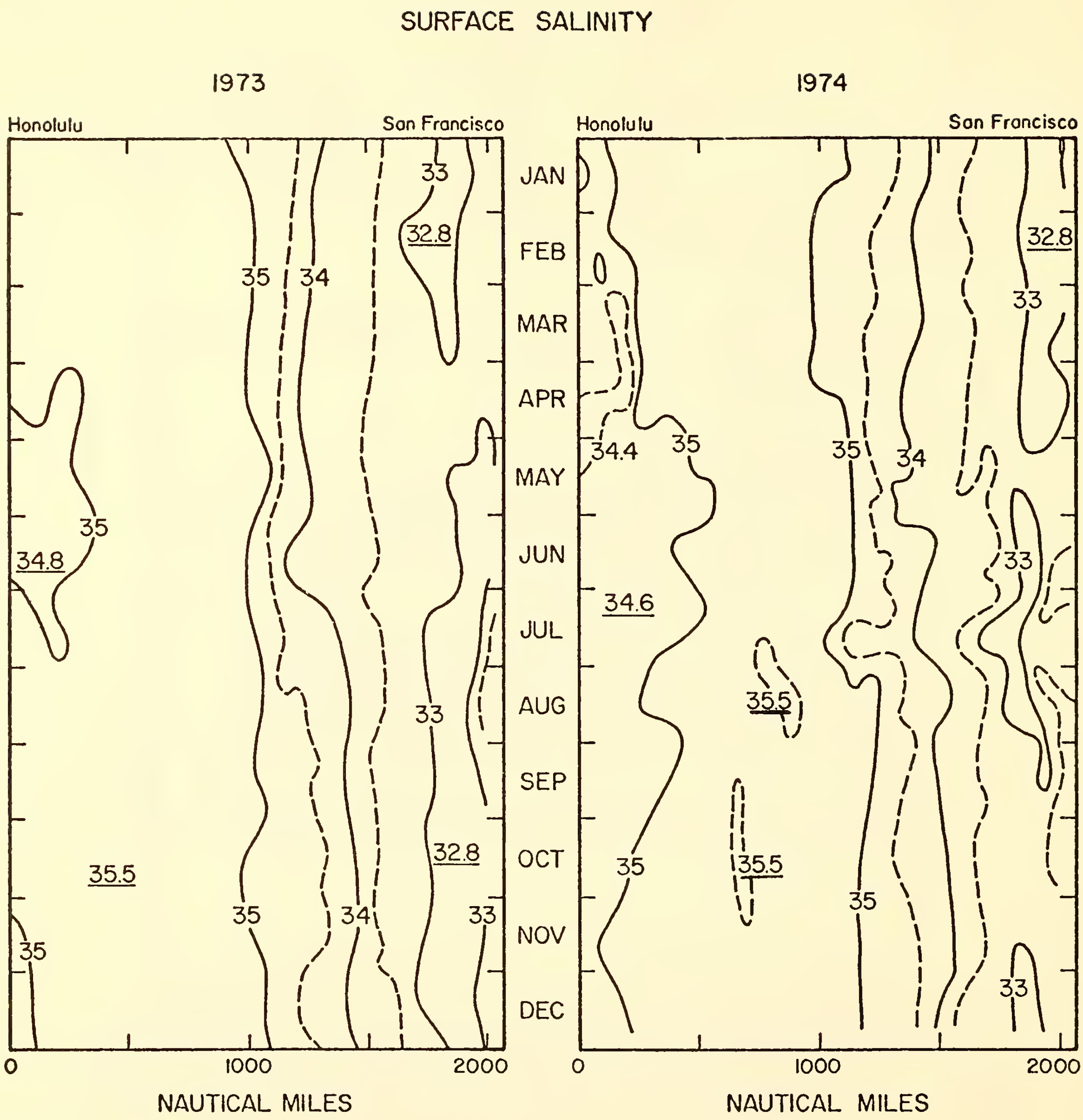

Figure 6.3. Temporal distribution of surface salinity on the great circle route between Honolulu and San Francisco, 1973 and 1974. Underlined values indicate maximums and minimums in the salinity field. Minimums occur both near Hawaii and in the California Current.

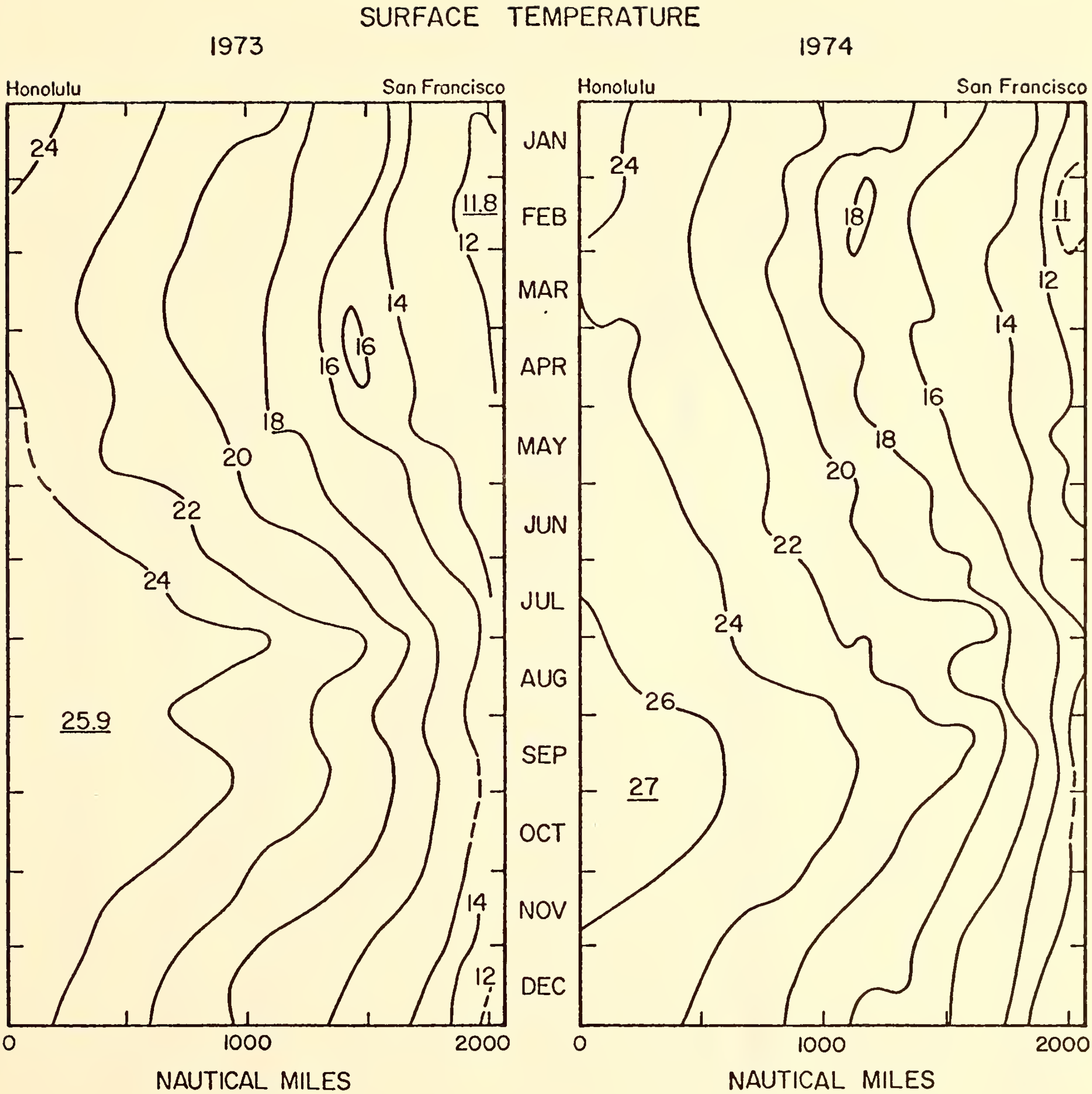

Figure 6.4. Temporal distribution of surface temperature on the great circle shipping route between Honolulu and San Francisco in 1973 and 1974. Underlined values indicate maximums and minimums in temperature field.

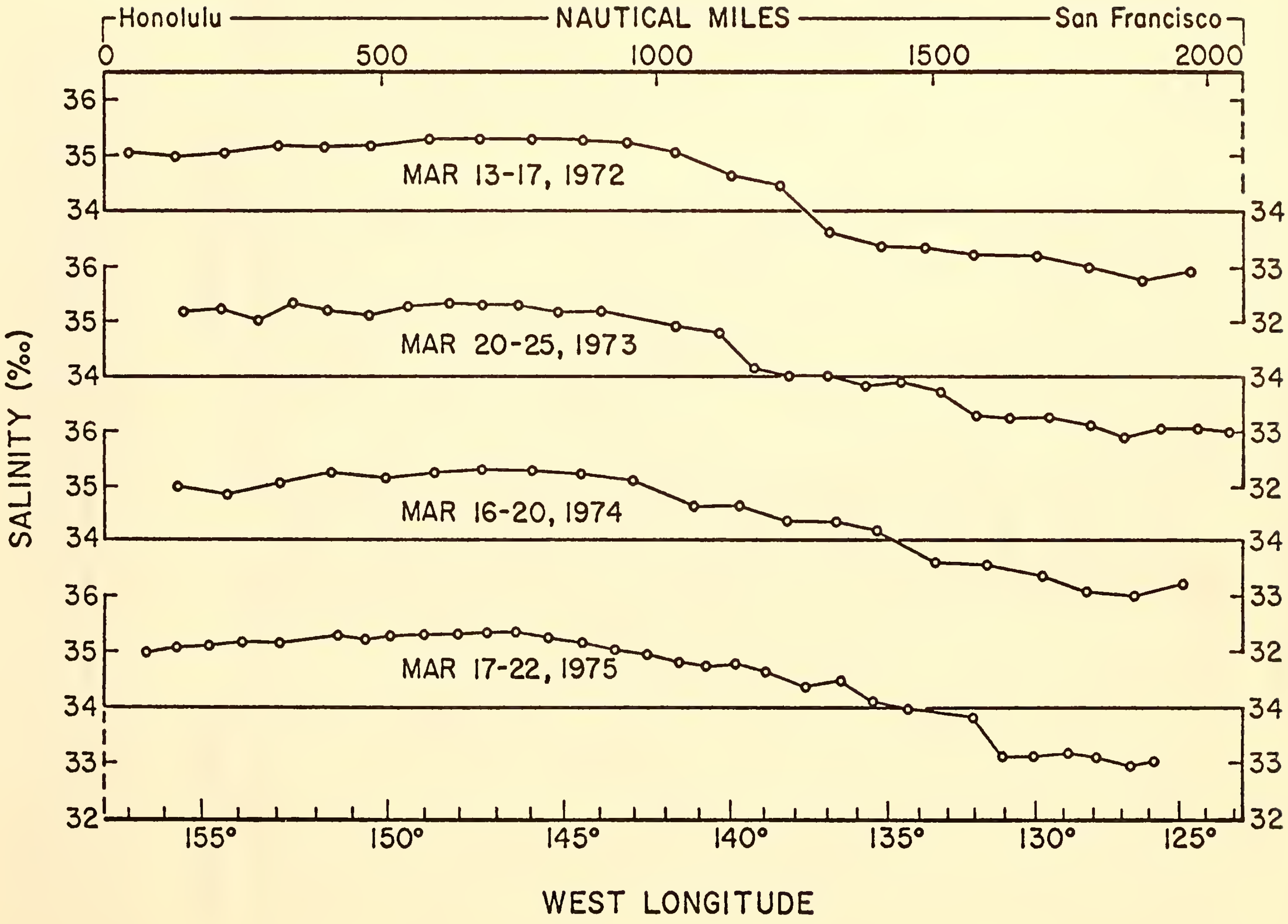

Figure 6.5 Horizontal profiles of surface salinity between Honolulu and San Francisco in the month of March for years 1972-1975.

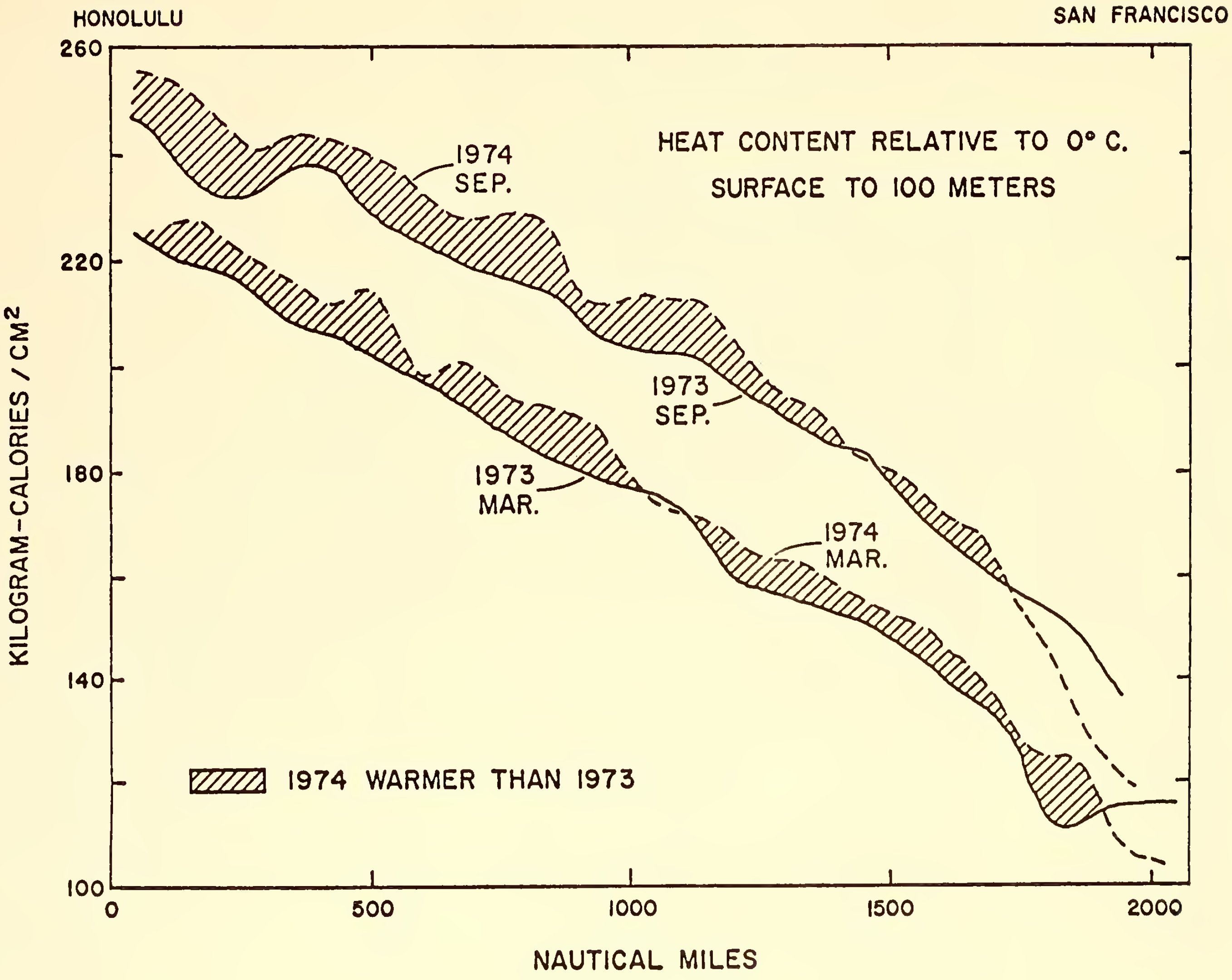

Figure 6.6 Heat content in the 0-100 meter layer for the months of March and September, 1973 and 1974.

ANOMALOUSLY COLD WINTERS IN THE SOUTHEASTERN BERING SEA, 1971-75

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and

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Introduction

Air and water temperatures during winter and spring periods since 1971 have been unusually cold over much of Alaska and the Bering Sea. The cold water has had numerous effects on terrestrial and marine organisms of the area, including a sharp decline of Bristol Bay sockeye salmon, *Oncorhynchus nerka*, stocks, which has been attributed to the cold weather. This paper will examine the cold years and document some apparent effects on dominant fisheries in the southeastern Bering Sea.

Meteorological and Oceanographic Conditions

Air Temperatures

The recent cold weather over the southeastern Bering Sea is well represented by the monthly air temperature anomalies at St. Paul Island (Fig.7.1) in the Pribilof group, which has reliable, long-period observations that indicate that the trend began in the winter of 1970-71. During the first quarter of 1971 the mean air temperature was 6.3°F

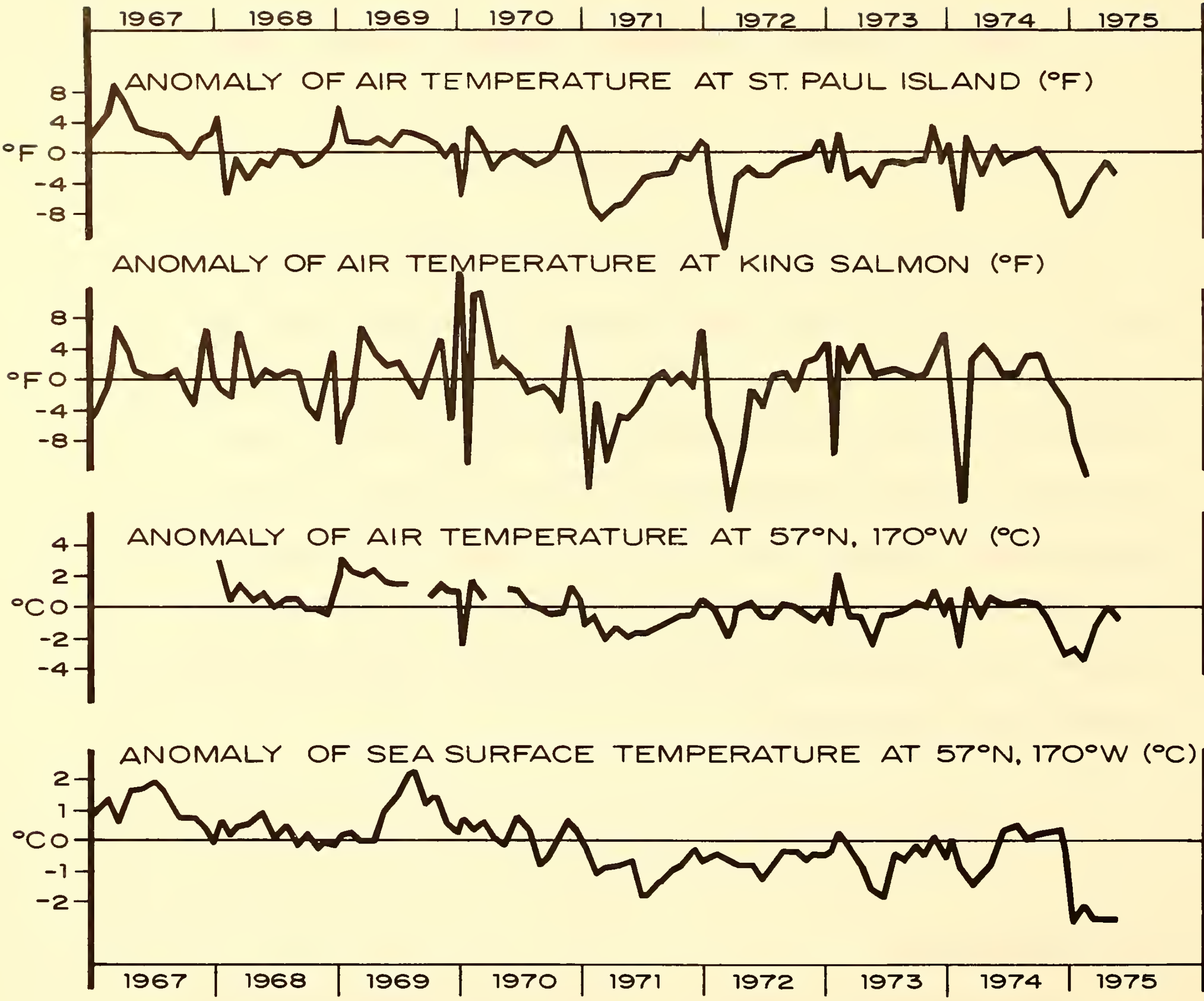


Figure 7.1 - Anomaly of air temperature and sea surface temperature in southeastern Bering Sea during 1967-75. Series 1 is anomaly of air temperature in °F at St. Paul Island, Alaska from 1941-70 mean. Series 2 is anomaly of air temperature in °F at King Salmon, Alaska from 1941-70 mean. Series 3 is anomaly of air temperature in °C at 57°N, 170°W (near St. Paul Island) from April 1962-May 1975 mean. Series 4 is anomaly of sea surface temperature in °C at 57°N, 170°W from January 1968-May 1975 mean. Data for Series 1 and 2 from National Climatic Center and data for Series 3 and 4 from Fleet Numerical Weather Central.

below normal, and the cold air temperatures persisted into the spring and summer of 1971--although normal conditions prevailed in the fall quarter. During the winter of 1971-72 cold conditions were reestablished; the -7.0°F temperature anomaly reached during the first quarter of 1972 was the lowest first quarter anomaly since published records began in 1934. Negative anomalies persisted into spring and summer but became positive during the fall quarter. Extremely low monthly anomalies of air temperature occurred in March 1971 (-9.1°F) and March 1972 (-13.1°F). Air temperatures during 1973 were more normal than either 1971 or 1972 with quarterly anomalies of only -1.2 to -2.7°F, but the seasonal cycle of anomalies was again similar to 1972 in that positive anomalies also occurred in the fall. Further, the cold anomaly was greatest in the spring quarter, rather than during the winter quarter as in 1971 and 1972. During 1974, anomalies were again below normal but not as extreme as those of 1971 and 1972 and were similar to 1973. Unlike the previous 3 years, however, cold conditions persisted in all quarters and were much colder than normal in the fall quarter. Conditions in 1975 so far have again been very cold and similar to the cold periods of 1971 and 1972. The greatest monthly negative anomaly of the winter of 1974-75 at St. Paul was in January 1975 (-8.5°F). Other anomalously cold winters have occurred at St. Paul in 1940, 1946, 1947, 1954, and 1956; unusually warm winters have occurred in 1935, 1937, 1950, 1966, and 1967.

King Salmon, near the head of Bristol Bay and about 10 degrees of longitude east of St. Paul Island, is another weather station in the southeastern Bering Sea where good quality, long-period weather records are available. The station, much more subject to continental air masses than the maritime St. Paul Island, has greater extremes of air temperature. The extremely cold winters since 1971 are evident in the data. The greatest quarterly anomaly (-10.3°F) occurred during the first quarter of 1972, but this was not a record low (as at St. Paul) because a similar negative anomaly had occurred during the winter of 1954. The years 1973 and 1974 were relatively mild at King Salmon compared to 1971 and 1972. Anomalies of air temperature were positive during the winter of 1972-73 except for January 1973 when a -9.7°F anomaly occurred. In the following winter positive anomalies occurred during all months except January and February when anomalies of -3.9°F and -16.2°F were observed. Summers were mild in 1973 and especially so in 1974. The winter of 1974-75 was again cold but unlike the cold winters of 1970-71 and 1971-72, marked cooling began in October rather than in January. Air temperatures in early 1975 have been colder than normal. The years of historically warm and cold winters at King Salmon are slightly different than those at St. Paul due to the different factors affecting its climate. Unusually cold winters occurred in 1954, 1956, as well as 1971 and 1972; warm winters occurred in 1944, 1955, 1958, 1960, and 1963.

Sea Temperatures

Observations of sea water temperature are not abundant in the southeastern Bering Sea, particularly during winter and spring. Johnson, McLain, and Nelson (1975) presented sea temperature anomaly data for the area 50 to 55°N, 160 to 165°W (Index Station 197-1) which indicate cold sea surface temperatures south of Alaska Peninsula since 1971. Straty (1974) reported sea temperature data near for the head of Bristol Bay during June and July for 1967, 1969, 1970, and 1971 which clearly reflect a lowering of sea surface temperature between 1967 and 1971; temperatures of 6 to 9°C at 10m. in June and July 1967 decreased to 0.5 to 4°C in June of 1971. Favorite and Ingraham (1973) reported unseasonably cold surface temperatures at the edge of the continental shelf in the eastern Bering Sea in spring 1971.

A summary of sea surface temperature and air temperature data fields are available from Fleet Numerical Weather Central (FNWC) for the area on a 12 hourly basis since 1962. These data represent analyses of temperature reports sent in by radio from merchant, naval, and other vessels as well as historical data. In these presentations, the actual origin of reports cannot be ascertained and, thus, one cannot tell if the values represent actual observations obtained in the 12 hour period or merely a long-term mean, or whether it was extrapolated from distant observations. In spite of these limitations, the fields provide a time continuity not otherwise obtainable and reflect relative changes of temperature with time. Monthly means of anomaly of air and sea temperature at a location near St. Paul Island (see Fig. 7.1) indicate that sea temperature anomaly lags behind the air temperature anomaly by a month or more.

The cold winters are also reflected in bottom temperatures obtained during annual surveys by the International Pacific Halibut Commission. These have been conducted on a fixed station grid in the southeastern Bering Sea in early June since 1966 (Best 1974), where a lowering of water temperatures was observed between 1967 and 1972 (Table 1). Temperatures recorded during June 1973 were 2 to 4°C above those of June 1972 or 1974 but are suspect as the mechanical bathythermograph did not function properly when tested after use. Fujii et al. (1974) showed that bottom water temperatures of less than 1.0°C did not occur offshore of Bristol Bay in the summer of 1967 but that temperatures of less than -1.0°C occurred in the summer of 1971, 1972, and 1973.

Ice Cover

Ice cover in the southeastern Bering Sea has been much more extensive during the winter and spring since the winter of 1970-71 than it was in the four previous winters. This is readily apparent in the duration of winter and spring ice cover in the eastern Bering Sea during 1966 to 1975 (Fig. 7.2). The extent of ice cover is divided into four common situations:

Table 1. Bottom temperatures in °C on line of trawl stations across Bristol Bay on IPHC Line No. 6 from Cape Seniavin near Port Moller to Cape Newenham. Data collected by International Pacific Halibut Commission from Best (1974) and personal communication.

TRAWL STATIONS

Date	Cape Seniavin							Cape Newenham		
June 1967	3.4	3.3	-	2.2	2.9	2.9	3.9	3.7	-	4.1
June 1968	No data									
June 1969	5.6	4.0	5.2	4.9	3.4	3.1	4.1	4.1	-	-
June 1970	1.4	2.1	1.7	0.5	0.9	2.5	1.3	1.6	1.6	1.7
June 1971	0.6	0.0	0.1	0.7	0.9	0.8	1.4	2.1	3.2	1.9
June 1972	1.1	0.3	-1.0	-0.8	-0.8	-	-	-	-	-
June 1973	3.9	-	2.1	2.4	3.0	3.4	-	-	-	-
June 1974	1.6	0.9	1.1	0.1	0.6	0.5	-	-	-	-
June 1975	0.6	0.0	-1.1	-1.1	0.6	0.6	-	-	-	-

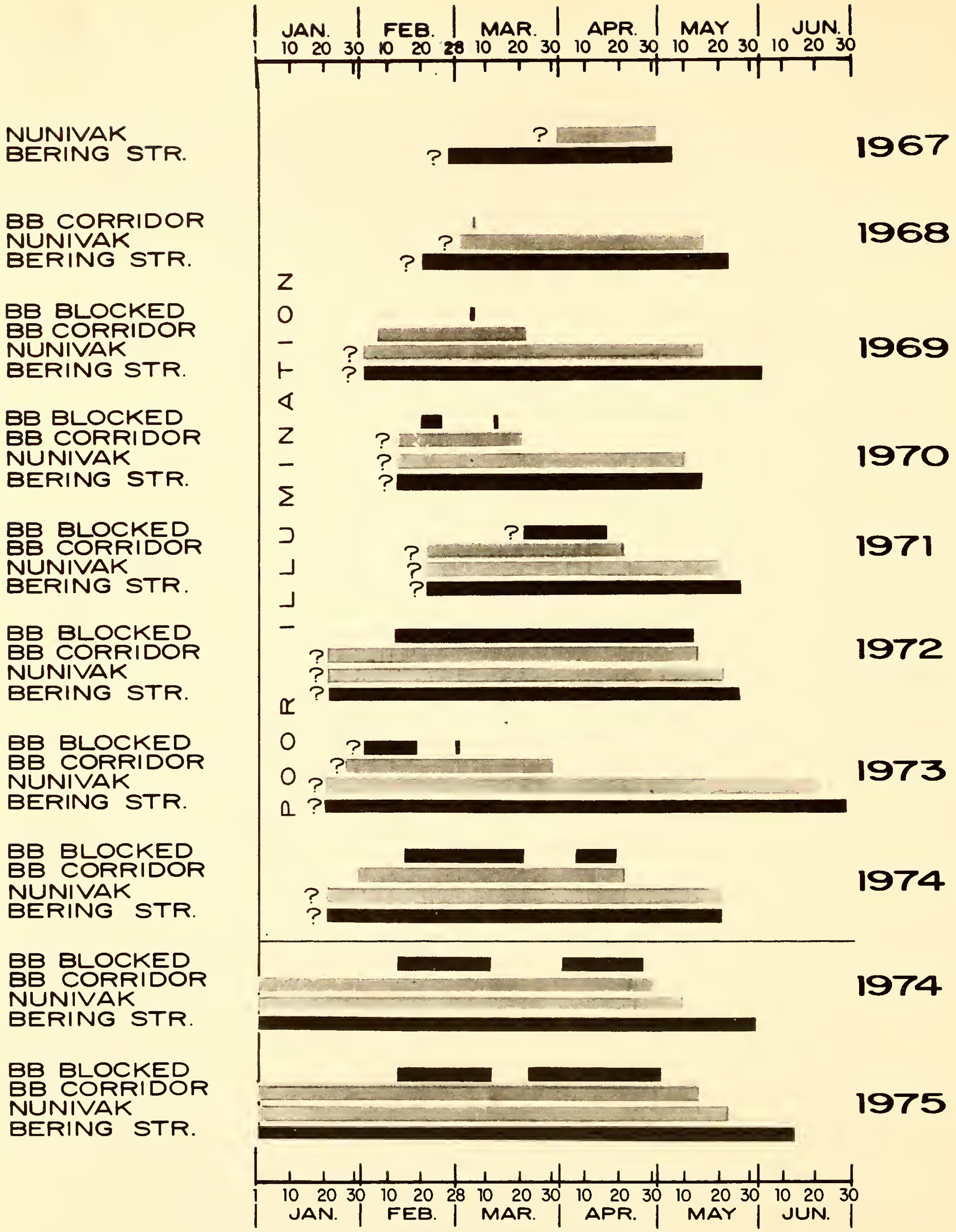


Figure 7.2 - Duration of 4 situations of ice cover (see text) in Eastern Bering Sea during winter and spring periods 1967-75. Data for 1967-74 (upper) from Dr. George Kukla, Lamont-Doherty Geological Observatory, Columbia University and data for 1974-75 (lower) derived from National Environmental Satellite Service information.

1) ice cover inside the Bering Strait or just north of it

2) ice margin joining the Alaskan coast near Nunivak Island with Bristol Bay free of ice

3) pack ice along northern shore of Bristol Bay with open water in southern Bristol Bay

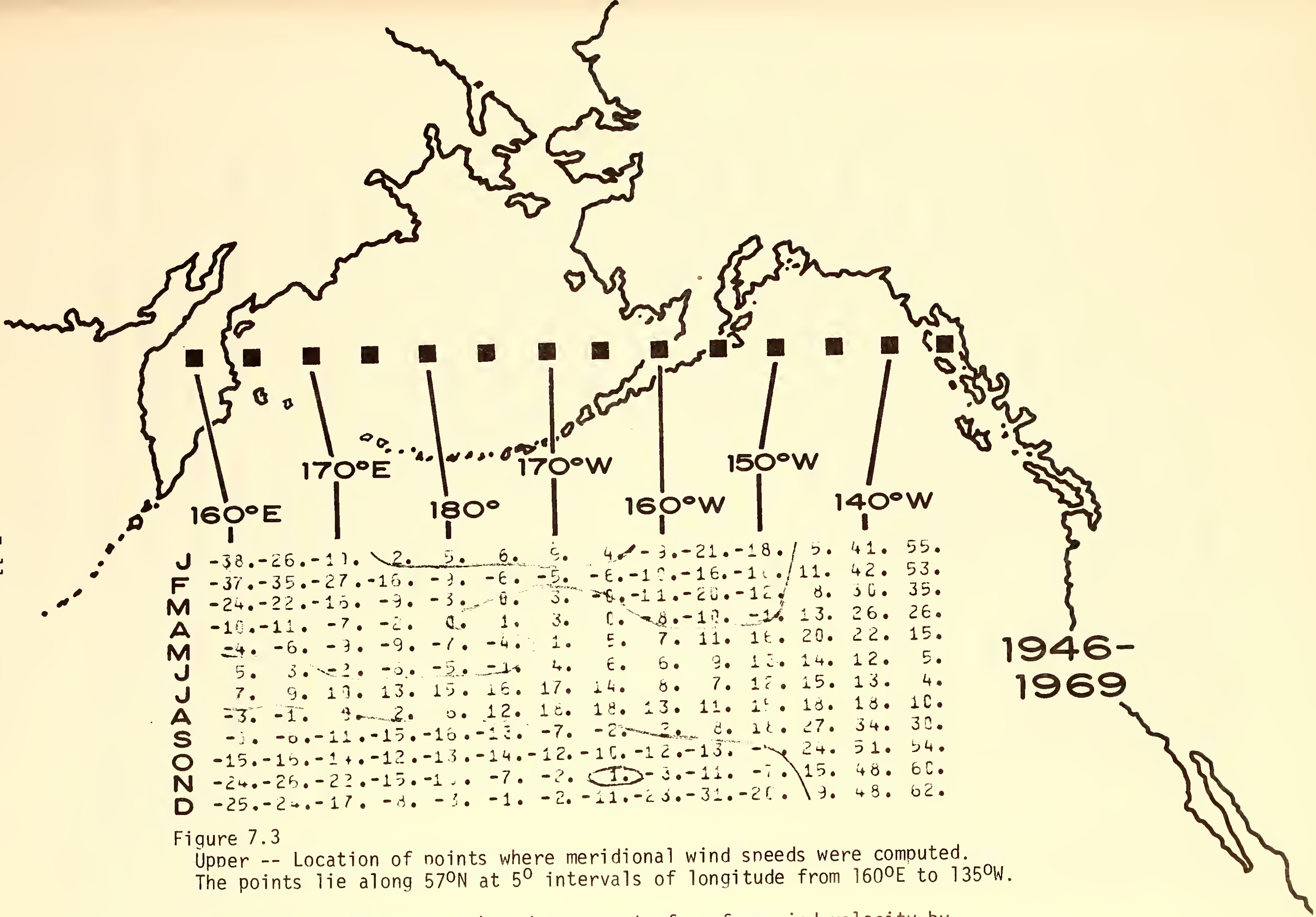
4) pack ice fully blocking Bristol Bay

These conditions were identified from satellite data by Dr. George Kukla of Lamont-Doherty Geophysical Observatory, Columbia University, for the period 1967 to May 1974 using weekly maps of average snow and ice cover of the Northern Hemisphere issued by the National Oceanic and Atmospheric Administration. To update the series, we used 2 to 5 day Experimental Ice Analyses of the Alaskan region issued by the National Environmental Satellite Service (NESS) during 1974 and 1975; these are summarized at the bottom of the figure in a similar manner as the previous data. Differences in interpretation are evident in the two sets of data for 1974.

In general, the ice cover was most extensive in early 1972 and 1975, less in 1971 and 1974, and still less in 1973. All 5 years had greater coverage than did the years 1966 to 1970. Kukla and Kukla (1974) describe similar increases in ice and snow cover over other areas of the Northern Hemisphere since 1971. In the Bristol Bay area the annual surveys of the International Pacific Halibut Commission during June 1972 and June 1975 have been limited by extensive ice cover. Also, Konishi and Saito (1974) show that drift ice in the Eastern Bering Sea extended farther south in 1971 than in 1967 and that in 1967 the ice disappeared earlier in the spring than normal. Ice cover was also extensive in 1956, when it extended westward from Bristol Bay to and beyond the Pribilof Islands.

Relation to Northerly Winds

Konishi and Saito (1974) have attributed the cause of the anomalously cold temperatures and ice cover in 1971 in the Eastern Bering Sea to unusually persistent northerly winds from March to May. They contrast this with 1967 when there was a predominance of winds from the south in May. To examine the relation of northerly winds to anomalously cold air and water temperatures, we computed a time series from January 1946 to May 1975 of monthly mean meridional components of the surface wind velocity on an east-west line of points at 5° intervals of longitude along 57°N across the southern Bering Sea and northern Gulf of Alaska (Fig.7.3). This series was based on monthly mean fields of surface atmospheric pressure developed by FNWC from two basic sources: from 1946 to 1963 the fields were developed from daily or more frequent pressure charts available from National Climatic Center or from National Center for Atmospheric Research; from 1963 to the present, digital fields of monthly mean pressure are available from means of 6 or 12 hourly analyses made by



J	-38.	-26.	-11.	2.	5.	6.	9.	4.	-3.	-21.	-18.	5.	41.	55.
F	-37.	-35.	-27.	-16.	-3.	-6.	-5.	-6.	-10.	-16.	[illegible]	11.	42.	53.
M	-24.	-22.	-16.	-9.	-3.	0.	3.	-8.	-11.	-20.	-12.	8.	30.	35.
A	-10.	-11.	-7.	-2.	0.	1.	3.	0.	-8.	-10.	[illegible]	13.	26.	26.
M	-4.	-6.	-3.	-9.	-7.	-4.	1.	5.	7.	11.	16.	20.	22.	15.
J	5.	3.	-2.	-6.	-5.	-1.	4.	6.	6.	9.	13.	14.	12.	5.
J	7.	9.	10.	13.	15.	16.	17.	14.	8.	7.	17.	15.	13.	4.
A	-3.	-1.	4.	2.	6.	12.	18.	18.	13.	11.	19.	18.	18.	10.
S	-3.	-6.	-11.	-15.	-16.	-13.	-7.	-2.	2.	8.	18.	27.	34.	30.
O	-15.	-16.	-14.	-12.	-13.	-14.	-12.	-10.	-12.	-13.	[illegible]	24.	51.	54.
N	-24.	-26.	-22.	-15.	[illegible]	-7.	-2.	1.	-3.	-11.	-7.	15.	48.	60.
D	-25.	-24.	-17.	-8.	-3.	-1.	-2.	-11.	-23.	-31.	-20.	9.	48.	62.

Figure 7.3

Upper -- Location of points where meridional wind speeds were computed. The points lie along 57°N at 5° intervals of longitude from 160°E to 135°W.

Lower -- Monthly mean northward component of surface wind velocity by point along 57°N and month for years 1946-69. Velocities are positive for southerly winds and negative for northerly winds in decimeters per second.

FNWC: The surface winds were computed by first interpolating the pressure fields to a regular grid with a spacing of 3 degrees latitude by 3 degrees longitude. Geostrophic winds computed on this grid were rotated 15° to the left and reduced in magnitude by 30% to approximate the surface wind. These winds are subject to a variety of errors such as relatively few original pressure observations over the Bering Sea (particularly during winter), to inaccuracies in the FNWC analyses and in the interpolation to the 3 degree grid, to inaccuracies in the computation of geostrophic winds and in their rotation and contraction to approximate the surface wind. This method is useful, however, in that it produces a reasonably consistent time series over many years over long distances.

The computed meridional wind velocities were variable by position along the line 57°N, by month of the year and from year to year. A long-term monthly mean of the velocities (for 1946-69) shows strong southerly winds over the eastern Gulf of Alaska that are generated by the low pressure systems, often over the Gulf. These southerlies are strongest in winter and greatly reduced in summer. In the western Pacific, northerly winds occur in winter, but these shift to southerly and reduce in velocity in summer. Meridional winds over the Bering Sea are more variable than over either the Gulf of Alaska or Western Pacific. Northerlies are common in fall and winter and southerlies are common in summer.

For brevity, the computed time series of meridional winds at the line of stations is not shown; these data show, however, that during 1966 and particularly during 1967, southerly as well as northerly winds were frequent over the Bering Sea but, during 1971 and later, southerly winds of speeds greater than 3.0 m/sec are much less common. In fact, during 1972, 1974, and the first 4 months of 1975 no strong southerly winds are evident over the Bering Sea region, and during the periods when they did occur (fall 1971 and summer and fall 1973), unusually cold air temperatures were not observed at St. Paul Island.

To compare the periods when southerly flow was frequent and rare, monthly mean meridional wind velocities for two contrasting 2 year periods, 1966-67 and 1971-72, (Fig.7.4) were obtained. General southerly winds characterize the former period over much of the southern Bering Sea during November to April, with variable north and south winds during May to October. In contrast, during the latter period, strong northerly winds are obtained from January to April or May, and winds during the remainder of the year are weak and variable. Particularly strong northerly winds are obtained over the southeast Bering Sea during February and March, the months of greatest negative air temperature anomalies at St. Paul Island during these years.

Table 2 shows a summary of the monthly mean northerly and southerly winds along 57°N for the two periods. During

1966-1967

	160°E		170°E		180°		170°W		160°W		150°W		140°W	
J	-47.	-45.	-16.	18.	25.	18.	19.	19.	2.	-27.	-33.	-9.	47.	68.
F	-60.	-49.	-3.	23.	31.	27.	26.	21.	9.	-9.	-13.	6.	44.	52.
M	-2.	-1.	13.	35.	37.	18.	8.	-4.	-31.	-58.	-42.	-10.	22.	24.
A	-13.	-21.	-15.	0.	10.	14.	18.	22.	22.	9.	3.	3.	3.	-6.
M	6.	7.	15.	11.	-7.	-10.	-12.	-14.	-13.	-5.	1.	8.	16.	22.
J	4.	3.	1.	-17.	-22.	-9.	4.	9.	10.	16.	22.	15.	1.	-6.
J	13.	14.	17.	25.	24.	15.	20.	23.	12.	2.	14.	19.	5.	-8.
A	1.	2.	1.	-2.	-5.	-6.	-2.	3.	10.	19.	35.	39.	29.	22.
S	-4.	-13.	-13.	-20.	-25.	-31.	-29.	-23.	-13.	5.	32.	49.	54.	54.
O	-7.	-15.	-14.	-7.	-12.	-27.	-32.	-29.	-31.	-38.	-15.	19.	44.	51.
N	13.	3.	3.	10.	11.	14.	18.	18.	9.	-2.	-5.	1.	24.	37.
D	-45.	-42.	-22.	-6.	-4.	10.	14.	-8.	-21.	-37.	-37.	-3.	49.	60.

1971-1972

J	-22.	-24.	-13.	5.	15.	9.	-2.	-10.	-20.	-39.	-41.	-20.	28.	46.
F	-23.	-30.	-23.	-16.	-22.	-41.	-50.	-48.	-44.	-37.	-14.	13.	42.	54.
M	-27.	-29.	-19.	-4.	5.	-3.	-11.	-18.	-31.	-52.	-39.	-4.	28.	38.
A	-5.	-7.	-5.	-2.	-3.	-13.	-19.	-21.	-23.	-24.	-7.	23.	44.	34.
M	9.	5.	-3.	-17.	-23.	-24.	-17.	-5.	9.	23.	39.	46.	40.	18.
J	11.	7.	-3.	-5.	-6.	-2.	0.	3.	9.	20.	26.	25.	15.	0.
J	5.	2.	-2.	-0.	2.	11.	20.	21.	15.	16.	17.	14.	5.	-9.
A	14.	12.	3.	-8.	-16.	-16.	-10.	-2.	3.	12.	17.	24.	30.	23.
S	-15.	-15.	-21.	-19.	-10.	4.	13.	11.	4.	1.	6.	15.	22.	14.
O	-4.	-2.	7.	7.	2.	1.	5.	4.	-1.	5.	19.	32.	44.	36.
N	-31.	-42.	-33.	-17.	-14.	-3.	13.	19.	9.	-6.	-11.	6.	38.	51.
D	-10.	-11.	9.	19.	14.	3.	3.	7.	3.	-8.	-14.	-2.	32.	49.

Figure 7.4 - Monthly mean northward component of surface wind velocity by point along 57°N and month for years 1966-67 and 1971-72. Velocities are positive for southerly winds and negative for northerly winds in decimeters per second.

Table 2. Summary of northerly and southerly meridional winds along 57°N for years 1966-67 and 1971-72. Velocities are positive for southerly winds and negative for northerly winds in decimeters per second.

	LOCATION													
Meridional Winds	Bering Sea									Gulf of Alaska				
Mean Speed	160°E		170°E		180°		170°W		160°W		150°W		140°W	
1966-67	17.6	18.8	12.6	14.5	17.8	16.6	16.8	15.4	15.2	18.9	21.0	15.1	28.1	34.1
1971-72	15.5	15.6	11.4	9.9	10.8	10.8	13.6	14.0	14.2	20.2	20.8	18.6	30.6	31.0
Meridional Winds from the North														
Mean Speed														
1966-67	25.4	26.6	13.7	8.7	12.5	16.6	18.8	14.0	21.8	25.1	24.2	7.3	-	6.7
1971-72	18.1	20.5	13.1	9.7	13.4	14.5	18.2	17.3	23.8	27.7	21.0	8.7	-	9.0
Number of Months														
1966-67	7	7	7	6	6	5	4	5	5	7	6	3	0	3
1971-72	8	8	9	9	7	7	6	6	5	6	6	3	0	1
Meridional Winds from the South														
Mean Speed														
1966-67	6.8	7.8	11.0	20.3	23.0	16.6	15.9	16.4	10.6	10.2	17.8	17.6	28.2	43.3
1971-72	10.5	6.0	6.3	10.3	7.2	5.6	9.0	10.8	7.4	12.8	20.6	22.0	30.7	33.0
Number of Months														
1966-67	5	5	5	6	6	7	8	7	7	5	6	9	12	9
1971-72	4	4	3	3	5	5	6	6	7	6	6	9	12	11
Displacement														
1966-67	-144	-147	-41	70	63	33	52	45	-35	-125	-38	137	338	370
1971-72	-103	-140	-99	-57	-58	-74	-55	-53	-67	-73	-2	172	368	354
Change	41	7	-55	-127	-121	-107	-107	-98	-32	52	36	35	30	-16

the cold period, 1971-72, the mean meridional winds were lower in absolute magnitude than during the earlier warm period, 1966-67, suggesting that the cold conditions were not caused by an increase in meridional wind velocities but were related to increased persistence of northerly winds. The meridional winds from the north were also of lower speeds during 1966-67 over most of the Bering Sea except in the Bristol Bay region where northerly winds were stronger during 1971-72. The number of months that northerly winds occurred was greater during 1971-72 than during 1966-67 over most of the Bering Sea except at 160°W near the head of Bristol Bay where northerlies occurred in 5 months in each period. Meridional winds from the south were much weaker during 1971-72 than during 1966-67 over all of the Bering Sea stations except at the extreme western end over Kamchatka.

By summing the speeds, we obtained the net displacement or resultant meridional wind. Here we did not correct for the varying number of days per month but this would be a minor correction. The net movement of air during 1966-67 was from the south over the central Bering Sea with northerly net flow over Bristol Bay and near Kamchatka. During 1971-72, however, net flow was from the north over the entire line in the Bering Sea and even the western two points in the Gulf of Alaska.

The last line in Table 2 shows the change in net displacement from 1966-67 to 1971-72 and shows that the reversal of wind directions between the two periods was centered in the central Bering Sea near 175°E and 180°.

Relation to Upper Air Circulation

The variability of meridional winds over the Bering Sea since 1966 is related to variations in the circulation of the upper atmosphere. The position of ridges and troughs are a particularly important aspect of the upper air circulation. In the Northern Hemisphere, a ridge in the upper air circulation causes warm, southern air to be advected to the north under its western flank and cold northern air to be advected to the south under its eastern flank. Thus when a ridge is centered to the west of a given point, winds are cold and northerly and when a ridge is east of the point, winds are warm and southerly.

Three processes occur which cause cooling of surface air and water temperatures in response to northerly winds. First, although the Coriolis effect causes a deflection of the water to the right of the wind, northerly winds cause flow of the surface water to the south. When meridional gradients of sea surface temperature exist, such southward water movements cause cold anomalies of sea surface temperature. A second factor causing cooling of the sea water is cooling by loss of sensible heat and latent heat of evaporation. These losses can be large when cold, dry air blows from land or ice covered areas over open water areas. Both processes are roughly proportional to the speed of the wind and to the vertical gradients of temperature and humidity, respectively.

A third process that would cool the sea water under northerly winds in the Bering Sea is that of increased southerly drift of ice.

The warm air advected into the Bering Sea region during 1966, particularly during 1967, was related to the occurrence of blocking ridges in the northeast Pacific centered to the east of the Bering Sea. Exceptionally strong southerly winds over the Bering Sea under the western flank of these ridges occurred during spring (March, April, and May) 1967 when a very strong ridge formed south of western Alaska. This ridge (Fig.7.5) was the strongest such ridge ever observed during the period of record--33 years (Andrews, 1968). The ridge combined with an unusually deep polar depression north of Alaska to drive the strong intrusion of southern air into the Bering Sea region. The effect of this upper level ridge at the surface was to shift the Aleutian Low westward over Kamchatka where its cyclonic motion contributed to the southerly flow of air over the Bering Sea. White and Clark (1975) describe the development of ridges over the central North Pacific and show that particularly strong ridges formed over the northeast Pacific during March, April, and December 1967 and January 1968. These were months of strongest advection of southerly winds at 57°N, 170°W near St. Paul Island. The ridges are often referred to as blocking ridges because the ridge blocks westerly zonal flow and causes meridional flow.

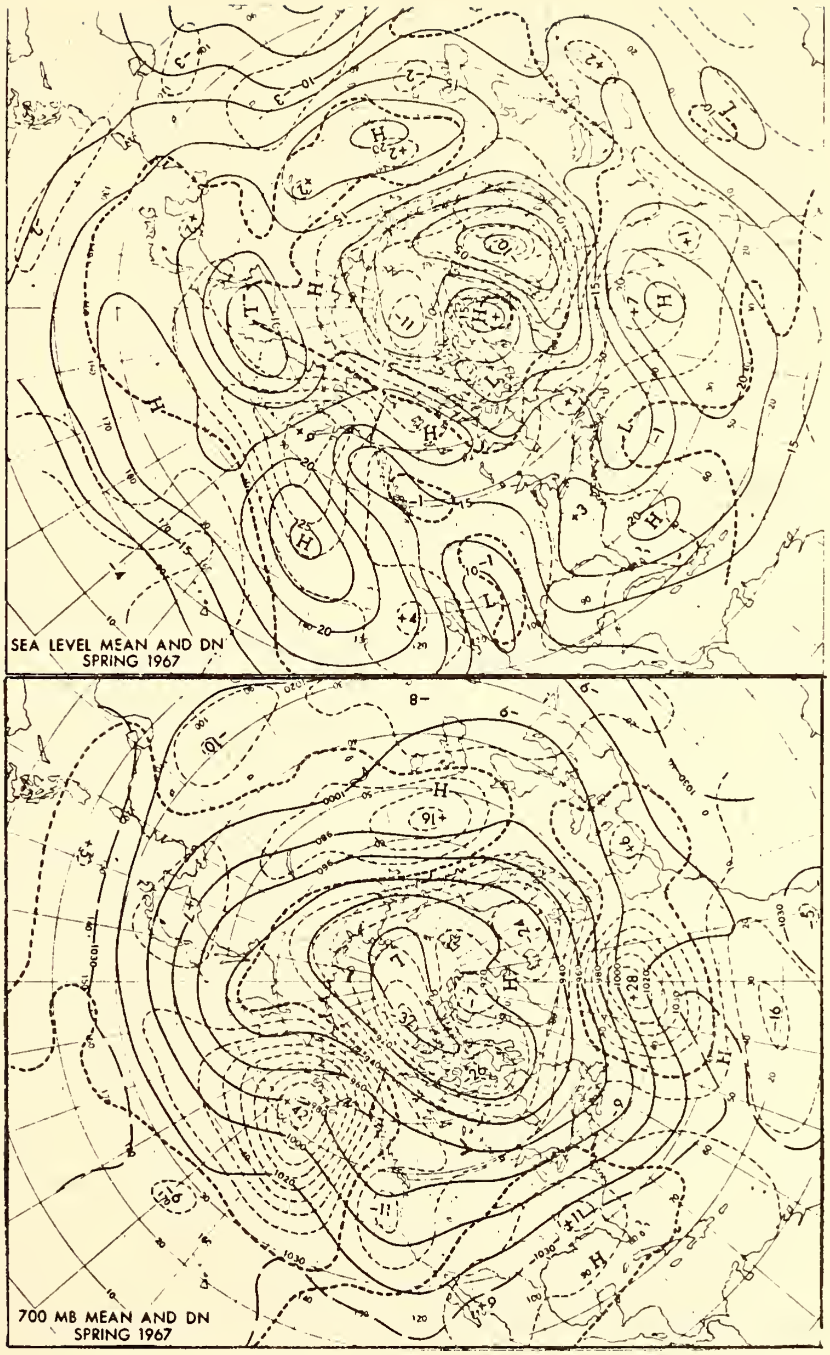


Figure 7.5- Mean sea level pressure, height of the 700 mb surface, and departures from normal for Spring 1967, (from National Weather Service).

The cold winters and springs in the southeastern Bering Sea since 1971 have been caused by the persistent occurrence of ridges or high elevation centers to the west of the Bering Sea over Siberia or the Arctic Ocean. These high pressure systems caused northerly winds over the Bering Sea under their eastern flanks. Associated with this westward shift of ridges since 1971 has been the frequent occurrence of troughs or low elevation centers over the Gulf of Alaska or northern Canada. During the cold winter of 1970-71, a blocking ridge formed over the western Bering Sea and extended to the northwest over the Laptev Sea north of Siberia. Anomalous circulation from the north occurred along the eastern flank of this ridge over the Bering Sea. By spring 1971 the blocking ridge had disappeared but was replaced by a strong low elevation center over western Alaska. Cyclonic circulation around this low again caused northerly winds over the Bering Sea. During the cold winter of 1971-72, a blocking ridge (Fig.7.6) again formed over the Bering Sea and northeastern Siberia as it had during the previous winter. Strong northerly anomalous winds occurred over western Alaska and the eastern Being Sea. Unlike the previous spring this situation persisted in spring 1972 and maintained northerly winds. The relatively mild winter of 1972-73 was different from the previous two winters in that weak southerly winds occurred over the Bering Sea under the western flank of a ridge over Alaska and western Canada. A

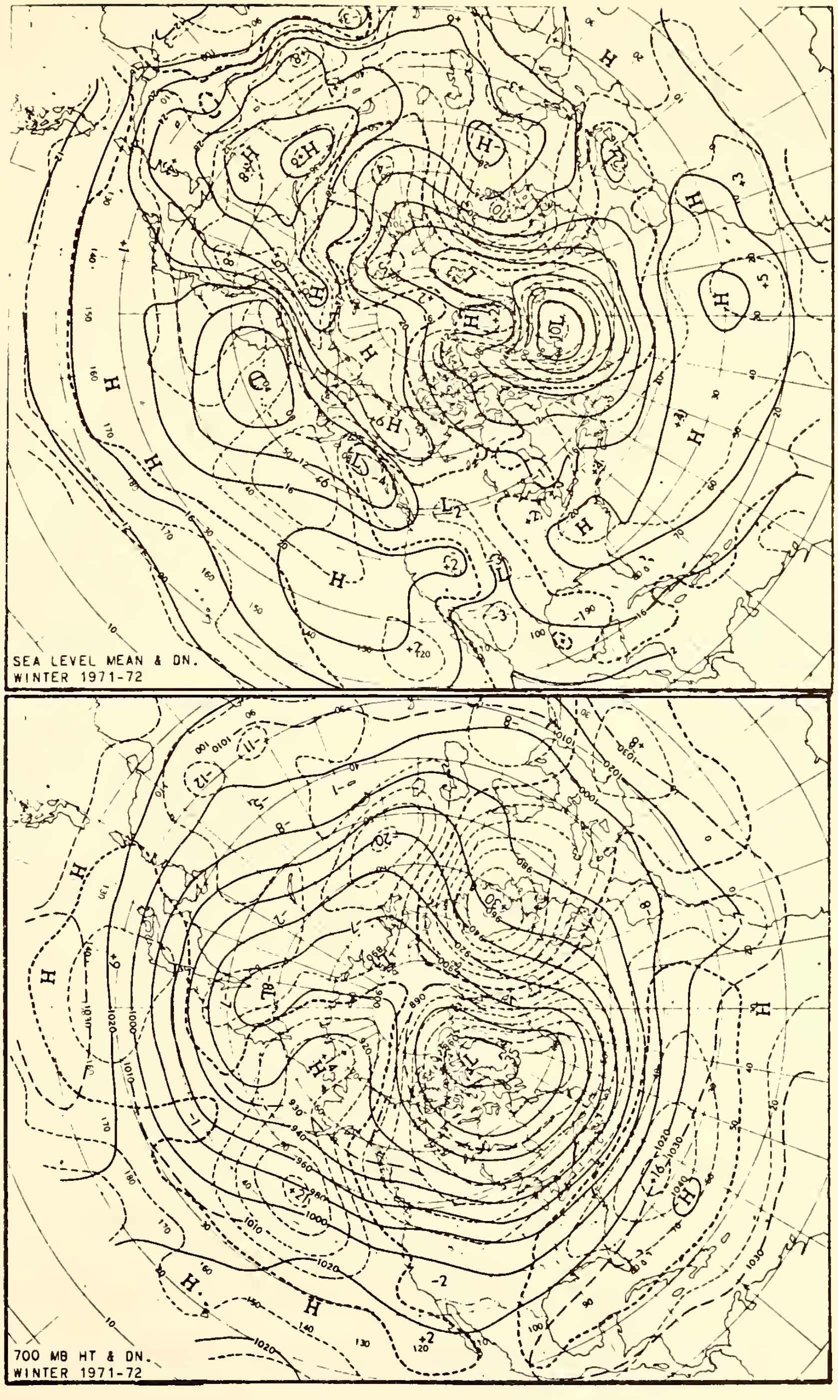


Figure 7.6- Mean sea level pressure, height of the 700 mb surface, and departures from normal for Winter 1971-72, (from National Weather Service).

strong low elevation center formed over Bristol Bay in the spring of 1973 and caused anomalous northerly winds along its western side over the central and western Bering Sea. The winter of 1973-74 was again cold. Again the pattern reverted to that of the winters of 1970-71 and 1971-72 with a strong high elevation region centered over northeastern Siberia and related anomalous northerly winds over the entire Bering Sea. The high over northeastern Siberia persisted into spring 1974 but the primary feature of the circulation was a low elevation region south of the central Aleutians. This low caused easterly winds over the southern Bering Sea and meridional winds were weak and variable, allowing the relatively mild temperatures and ice cover that spring. The winter of 1974-75 again had persistent strong northerly winds over the southeastern Bering Sea in response to a continued high elevation center over northeastern Siberia and a low elevation center over western Alaska.

Relation to Hemispheric Circulation

We have seen that the cold winters and springs since 1971 in the southeastern Bering Sea have been caused by a westward shift of ridges or high pressure systems and related occurrence of troughs or low pressure systems to the east. These systems create air flow from the north which cools the region by heat loss and by southward transport of air, water, and ice.

This westward shift of high pressure systems is associated with other atmospheric fluctuations elsewhere. For example, since 1971 the high pressure systems occurring in northeastern Siberia have been associated with either a strengthening of the polar depression or a shift of its principal lobe to the south over northeastern Canada or Baffin Bay. Concurrent with these changes has been a general strengthening of high pressure systems in the mid-latitudes. Thus winters since 1970-71 have had stronger meridional gradients of height, hence stronger zonal winds. Wagner (1975) mentioned that the winter of 1973-74 was the fourth consecutive winter in which the zonal atmospheric circulation over most of the western half of the Northern Hemisphere has been stronger than normal. This suggests that a teleconnection exists between strong mid-latitude, westerly winds over North America and cold winters in the Bering Sea region.

The cold winters over the southeastern Bering Sea since 1971 were also associated with major shifts in the patterns of sea surface temperature in the North Pacific Ocean. In 1972 Namias (1972) pointed out that in the winter of 1971-72 the coastal waters along the entire West Coast from California were anomalously cold, while a pool of warmer than normal water was present in the east central North Pacific. In contrast, during the 14 winters previous to 1971-72 the general sea surface temperature pattern was the opposite:

warm along the West Coast of North America and cold in the central North Pacific. Namias also suggested that the winter of 1971-72 may have started a new pattern that would persist for several years. This appears to have been a good prediction as it has persisted for 5 winters now. How long the new pattern will persist is, of course, unknown.

Effects on Fisheries

Salmon

According to preliminary reports of the Alaska Region of the National Marine Fisheries Service (Anon. 1974), the 1974 commercial harvest of Pacific salmon, *Oncorhynchus* spp., may have been the lowest since the inception of the Alaska salmon fishery in the late 1800's and followed almost equal low catch in 1973. The low statewide catch was reportedly due to poor catches of pink salmon, *O. gorbuscha*, which were attributed to the continued effects of the unusually severe winters of 1970-71 and 1971-72.

Pink salmon spawn in many streams of southern and western Alaska. The adults spawn in summer, or fall, the eggs mature in the stream beds over winter, and the juvenile fry migrate to sea the following summer. Salmon eggs are susceptible to cold winter weather by ice-caused erosion of the spawning beds and by reduced flow of water through the spawning gravel and consequent reduction in supply of oxygen to the eggs.

In contrast to the pink salmon which migrate directly to sea following their emergence from the spawning gravel, sockeye salmon, _O. nerka_, typically spend 1 or 2 years as juveniles in a lake before migrating downstream to the ocean. A large population of sockeye salmon spawn in rivers tributary to Bristol Bay that have lakes within their watersheds; these salmon have constituted a very important fishery in the Bristol Bay region since the turn of the century. Catches of sockeye salmon in Bristol Bay during 1972 to 1974 were the lowest on record since 1896 due to the fishery being severely restricted to obtain desired escapement levels. This caused adverse effects on the economy of the area.

The cold air temperatures observed at King Salmon during the first 6 months of 1971 and 1972 had various apparent effects on the Bristol Bay sockeye salmon. Mature sockeye salmon returning to Bristol Bay streams to spawn were 1 to 2 weeks late in 1971, which caused considerable concern that the run would be much smaller than predicted. Although there is no specific evidence as to the manner by which cold oceanic conditions may have affected the onshore movements in 1971, large catches of mature salmon by research vessels in another year of anomalously cold shelf temperatures, 1956, indicated that onshore migrations may be delayed until near surface waters over the shelf have warmed to 3°C or higher (INPFC, 1958).

A number of anomalous phenomena were noted in Lake Iliamna in the summer of 1971 following the cold winter of 1970-71 (Mathisen, et al. 1972)[1/]. The lake ice melted about 3 weeks later than normal, and colder than normal conditions existed throughout the summer. A heat budget study indicated that stored heat in Lake Iliamna in June (Fig.7.7) was not only the lowest recorded since 1961 when records began, but also was only half the maximum value recorded during that period. The heat stored in Lake Iliamna in June is inversely correlated with timing of the escapements of sockeye to the Kvichak River which were 8 or 9 days later in 1971 than in 1970. A delay of 5 to 7 days in the peak of spawning was observed on the spawning grounds.

The effects of cold temperatures on the abundance of sockeye salmon are probably of greater importance at the egg and juvenile stages than at the adult stages. Mathisen et al. (1975)[2/], as a result of numerous studies of sockeye salmon in the Kvichak River and its source Lake Iliamna, state that "temperature strongly affects hatching, emergence, and subsequent growth and survival of juvenile sockeye salmon." The cold winter of 1970-71 caused a reduction in both number of fry produced in the spawning streams and in the growth of the fry in the Kvichak River District. Although there was a 65% increase in the number of spawners (13.9 vs 8.4 million) in 1970 over 1969, the relative fry production as measured in 1971 was only 52% of that of the previous year, in fact,

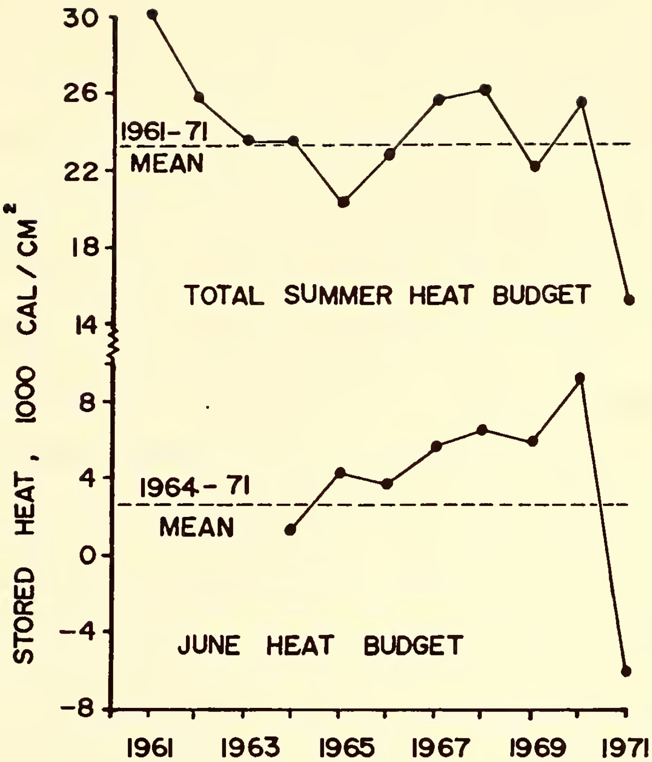


Figure 7.7 - Amounts of stored heat in excess of 4^{o}C in June from 1964 through 1971 and total summer heat budgets (in August / September) from 1961 through 1971, Lake Iliamna, Alaska. Data from Mathisen, et. al., 1972.

the lowest recorded since sampling began in 1961. Also the mean length of fry in September 1971 was the lowest on record since sampling began--about 21% less than the mean length for 1962-70. Factors related to overstressing of the ecosystem by number of spawners are also of importance in fry production and growth, but such factors may be of less importance than the cold weather of the winter of 1970 and 1971. For example, although the number of spawners producing the 1965 brood year (24.3 million) was almost twice that of the 1970 brood year (13.9 million), reduction of the mean length of fry at age 0 was only 7% for the 1965 brood year as opposed to 21% less for the 1970 brood year--according to data presented by Mathisen, et al., (1974)[3/]. They also reported that the cold winter of 1971-72 also resulted in poor growth of sockeye fry in the Kvichak District. The mean length of age 0 fry in the summer 1972 was the second lowest on record since sampling began in 1961. The winter of 1972-73 was not extremely cold and mean lengths of age 0 fry in the Kvichak District were near the average length for 1962-70.

The poor return of mature sockeye salmon from the 1969 brood year to the Bristol Bay inshore fishery in 1973 was "attributed to poor marine survival as a result of the severely cold winter of 1970-71 and the subsequent late spring of 1971" (Mathisen, et al. 1974); even poorer initial returns from the 1970 brood year were reported (Mathisen, et al. 1975). However, returns from this brood year are not complete even at this time. Fujii et al. (1974) discussed the poor return of sockeye salmon to Bristol Bay in 1973 and attributed the low catches to cold sea water temperatures in the southeastern Bering Sea in 1971.

The winters of 1973-74 and 1974-75 were again very cold and should cause similar effects on the Bristol Bay sockeye populations as did the winter of 1970-71. According to Rogers, et al. (1975)[4/], conditions in the Wood River Lake system of the Nushagak District of Bristol Bay indicated that the winter of 1973-74 was colder than average for the fourth consecutive year; they also note that cold temperatures in winter generally results in poor survival in the Wood River Lakes where spawning occurs primarily on the beaches It should be pointed out that delayed spring conditions may have more severe effects than cold winters.

Temperatures in spring and summer 1974 were much warmer than normal and ice breakup occurred 10 days earlier than normal in the Wood River area. The mild conditions resulted in rapid growth of the juvenile sockeye which evidently more than compensated for poor growth rates during the previous winter. Rogers, et al. (1975) noted that mean size of sockeye salmon fry in June 1974 was the largest since such observations were started in 1962. Mathisen, et al. (1975) also reported unusually warm air temperatures in spring 1974 in the Lake Iliamna area and one of the earliest

The relative abundance of 3-year old halibut is considered to be the best indicator of year class strength; in 1974, the rate of capture of the 1971 year class was the lowest for the age group since the surveys began. The 1972 year class was present in below average numbers at both inshore and offshore station. (Reeves, MacIntosh and McBride, 1974)[6/].

King Crab

The effect of cold water conditions on the abundance of king crab, Paralithodes camtschactica, in the eastern Bering Sea is an enigma. Estimates of male abundance by the Northwest Fisheries Center from a fixed grid of stations over the continental shelf in 1968, 1969, 1970, 1972, and 1973 (Fig.7. 8) indicate low numbers of small and medium length crabs in 1968, 1970 and 1972 (note no data for 1971) and 2-3 times as many crabs in 1969 and 1973. (Hayes and Reid, 1973)[7/].

Crab growth from 0 to 5 years is largely linear, from 0 to 100 m; thus, it would appear that 1968 was an exceptional spawning year, but discrepancies in the related abundances of specific year classes in individual years severely challenges the consistency of these data. It is not clear at this time whether this is another case of organisms moving out of the standard sampling area as a result of environmental conditions, reaction of the organism to sampling gear, or inadequate sampling methods. Beardsley[8/] believes that if there is a temperature/recruitment relationship, cold temperatures

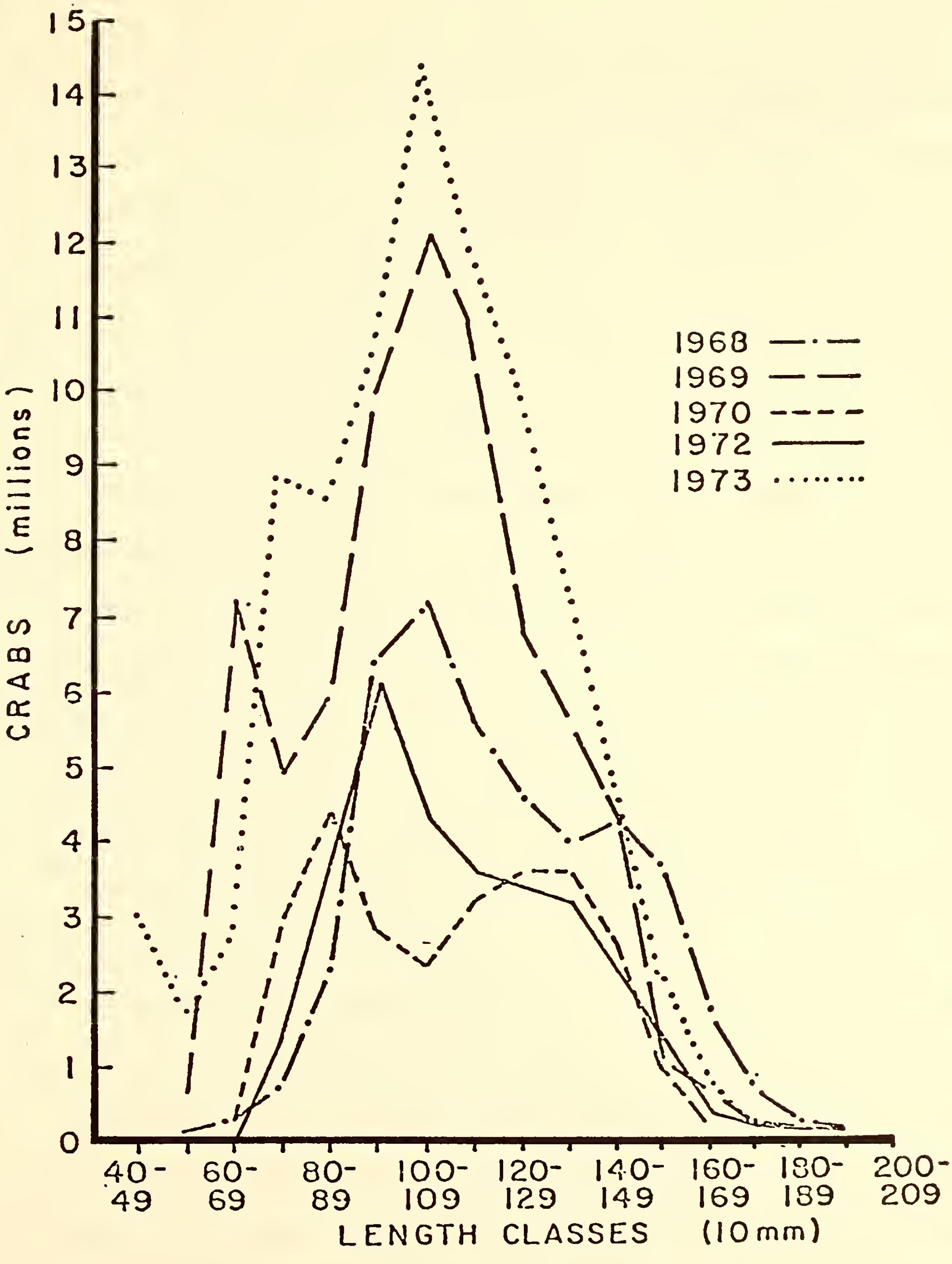


Figure 7.8- Estimates of male king crab abundance by 10 mm length classes from the 1968, 1969, 1970, and 1972 spring research cruises of the NMFS Northwest Fisheries Center in the Eastern Bering Sea.

breakups of ice on Lake Iliamna, as well as exceptionally high water temperatures and low lake level in summer 1974.

Halibut

Another species of fish affected by the recent cold winters is the Pacific halibut. Hippoglossus stenolepis. Pacific halibut are a demersal species which spawn in winter over the continental slope and move into the shallow continental shelf waters in spring to feed when water temperatures rise. The halibut fishery is largely restricted to waters in the 3-8°C temperature range. Data from the annual trawl surveys by the International Pacific Halibut Commission in the southeastern Bering Sea on a fixed station grid since 1966 document the lowering of bottom water temperatures from 1967 to 1972. Based on these surveys, the southward extent of the 2°C isotherm in 1972 was considered to inhibit the migration of halibut to the usual summer feeding grounds (Best, 1974)[5/]. Normally 2-year old halibut are a significant proportion of the catch in the nearshore, shallow water stations along the north shore of the Alaska Peninsula, and 3-year old halibut dominate the catches in Bristol Bay. However, in 1972, the catch rate of the 3-year old halibut (the 1969 year class) in the inshore area was four times the average. It was reported that the distribution of 3-year old halibut had shifted far enough inshore to be partially bypassed by the standardized station grid, thus resulting in an underestimation of their abundance.

may increase the number of crabs, but there is not much evidence for any specific relationship at this time. Nevertheless, there is evidence that a strong year class of king crab was produced in 1970 or 1971.

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FOOTNOTES

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OCEANOGRAPHY AND ALBACORE TUNA, *THUNNUS ALALUNGA* (BONNATERRE), IN THE NORTHEAST PACIFIC DURING 1974

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Oceanography and Albacore Tuna, Thunnus alalunga (Bonnaterre), in the Northeast Pacific During 1974*

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The early-season distribution and apparent abundance of the North Pacific albacore tuna, Thunnus alalunga (Bonnaterre), are apparently related to oceanographic conditions of the Transition Zone and associated oceanic frontal structure. Results from fishery-oceanography research cruises conducted cooperatively by the NOAA/NMFS Southwest Fisheries Center and the American Fishermen's Research Foundation show that the relative abundance of albacore is greater within the Transition Zone than outside it during their migration through offshore waters and that year-to-year variations in ocean structure are reflected in variations in albacore distribution (Laurs and Lynn, 1974, 1975). It also appears that the migration patterns of albacore in the offshore waters are important in determining the subsequent distribution of fish in inshore waters during the usual fishing season.

Transition Zone and Associated Frontal Structure

The Transition Zone is a region of mixing between cold, low salinity subarctic waters to the north and warm, saline subtropic waters to the south (Sverdrup, Johnson and Fleming, 1942). The Transition Zone waters are found in a zonal band across the North Pacific middle latitudes within

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the westward-flowing North Pacific Current (McGary and Stroup, 1956; Roden, 1971). They are bounded at the north by the subarctic front and at the south by the subtropic front (Roden, 1974). Both of these fronts have abrupt gradients in temperature and salinity. The dynamic processes which produce and maintain the gradients also enrich these waters (McGary and Stroup, 1956), which give reason why these regions are biologically important to albacore. To the east of 135° W, the North Pacific Current turns southeast and south as does the Transition Zone, and the boundary gradients begin to lose their continuity.

Temperature and salinity data are used to identify the Transition Zone as distinct from the water masses to the north and south. Three oceanographic sections of the vertical distribution of temperature and salinity along 137°30' W taken in June of 1972, 1973, and 1974 are given in Figure 1. In this figure, subarctic waters are depicted by hatching-shading of salinity less than 33.8‰, subtropic waters by dot-shading of salinity greater than 34.2‰, and Transition Zone waters by no shading; the temperature field, shown by dashed lines, is simplified to the 62° F (16.7° C) and 58° F (14.4° C) isotherms. In 1972 and 1973, the subarctic waters were found north of 35° N and the subtropic waters south of 31°30' N and 32° N, respectively. The boundaries of the Transition Zone between these water masses were well-developed and readily identifiable. The subarctic front was marked by the sharp shoaling of the 33.8‰ isohaline and 58° F (14.4° C) isotherm and abrupt gradients in salinity extending from the surface to 200 m where a strong halocline was evident. The subtropic front was delineated by the steep shoaling of the

34.2‰ isohaline and 62° F (16.7° C) isotherm and marked gradients in salinity extending from the surface to 200 m where a well-developed halocline was apparent. Mixing was indicated in the Transition Zone in 1972 with low-salinity water penetrating southward and some high-salinity water northward at intermediate depths. This distribution and those along other meridians, indicate that a large wave-like feature or large eddy existed in the Transition Zone region centered at about 137°30' W.

Oceanographic conditions were different in the region of the Transition Zone in 1974 from those which were observed in 1972 and 1973 (also see Saur, Sec. 6). In 1974, subarctic waters were found north of 36°30' N with a lens of Transition Zone water between 37° to 39° N extending from the surface to 100 m, and extending in a tongue southward between 36°30' N and 34°30' N at intermediate depths. Subtropic waters were found south of 33°30' N and in a small, shallow lens at the surface near 35° N. The boundaries of the Transition Zone were poorly developed and broken. The subarctic front was virtually non-existent and the Transition Zone waters graded gradually into the subarctic waters. The subtropic front was weak, but not as weak as the subarctic front. The salinity gradients were more diffuse and the changes in depth of the isotherms more gradual and variable in the regions of the subarctic and subtropic fronts in 1974 than in 1972 and 1973. These year-to-year differences match the findings of J. F. T. Saur using independent data.

Albacore Catches in Relation to Oceanic Fronts

During June 1972 and 1973, commercially productive centers of fishing developed in Transition Zone waters between 33° to 35° N and west of

135° W with small or no catches made in the region between the offshore area and inshore waters within 150 miles of the coast where fishing takes place during the traditional albacore fishing season. These fishing centers persisted for 2 and 3 weeks before fishing effort was withdrawn. In these years, the frontal structure was strongly developed and the Transition Zone easily identifiable.

During June 1974 when the frontal structure was poorly developed and the boundaries were less distinct, the catches were more scattered and distributed over a large range of latitude, 31° to 36° N, and longitude. High catches were made in the area offshore of 135° N, and also in the region between the offshore area of high catches and inshore waters where fishing normally takes place. Catches were substantial in 1974, however, they did not demonstrate persistence in any area for more than a few days, and more search time was required in 1974 than in the previous 2 years, to make catches. There was one area which did have abrupt gradients during June 1974. An eastward protruding tongue of Transition Zone water was found centered at 35°30' N, 132°30' W which had salinity gradients comparable to those found in previous years. Substantial catches of albacore persisted in this region for a week until fishing effort was withdrawn.

Summary

The influence of extensive lateral mixing between water masses and the diffuse nature of the boundary frontal structure apparently was not effective in concentrating albacore in offshore waters during early-season 1974 as had occurred in the previous 2 years.

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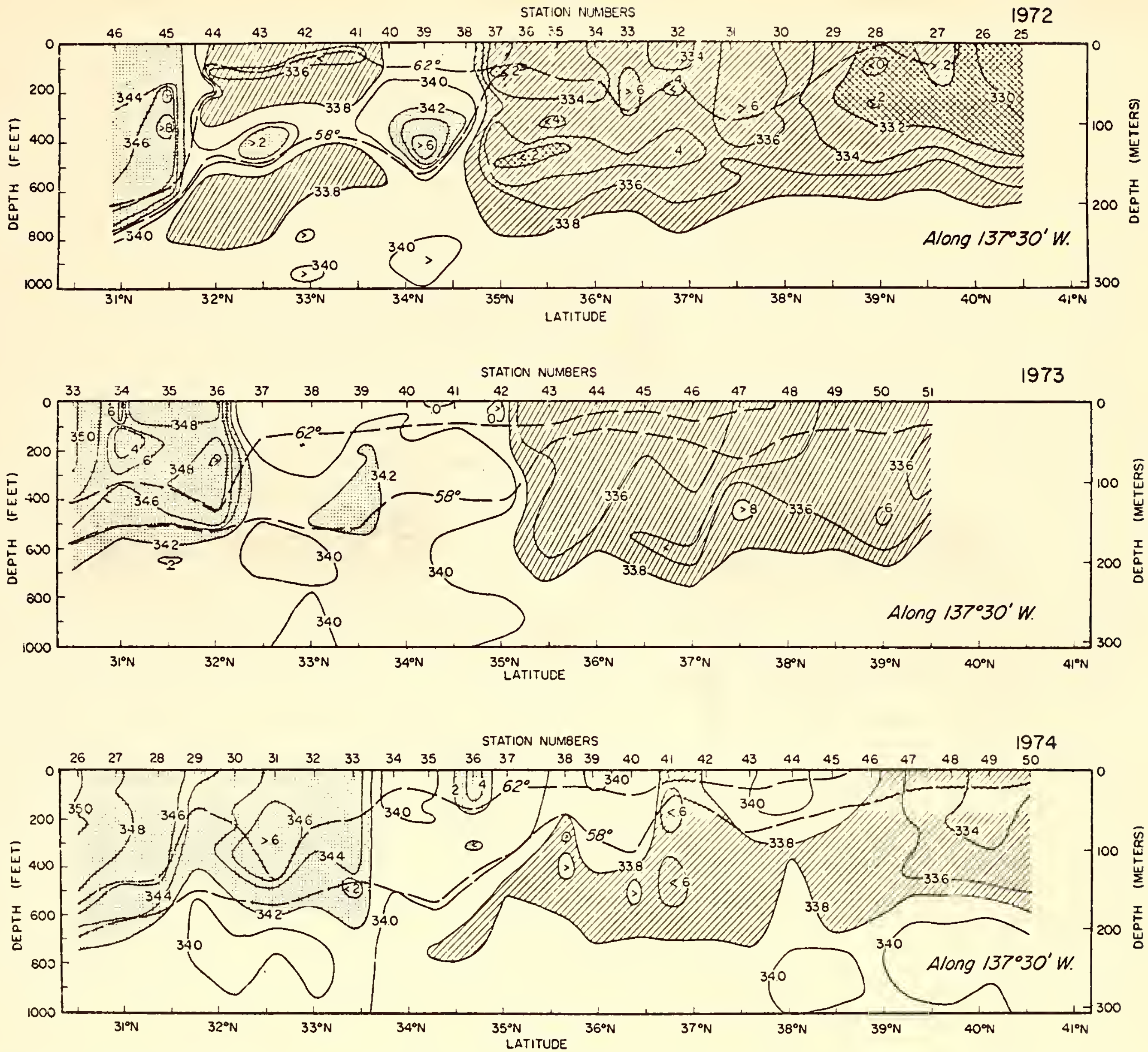

Figure 8.1 Vertical sections of salinity along 137°30' W for June of 1972 (upper), 1973 (middle), and 1974 (lower). Subarctic waters depicted by hatch-shading of salinity less than 33.8°/oo, subtropic waters by dot shading of salinity greater than 34.2°/oo, and Transition Zone waters by no shading. The 58°F (16.7°C) isotherms are shown by heavy dashed lines.

SEA SURFACE TEMPERATURES IN THE EASTERN TROPICAL PACIFIC DURING 1974 AND THE TROPICAL FISHERY

by

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The eastern tropical Pacific supports a major part of the international fishery for yellowfin and skipjack tuna and it also supports the world's largest anchoveta fishery which is found on the eastern boundary of the tropical Pacific. According to the Inter-American Tropical Tuna Commission's 1974 Annual Report[1] over 300,000 tons of yellowfin and skipjack were captured during 1974 in the eastern tropical Pacific east of 150°W. The catch of yellowfin was the largest in the history of the fishery; and the skipjack catch was nearly 17,000 tons above the average of the previous five years.

Published literature covers in detail the latitudinal range of several species of tropical tunas in terms of sea surface temperatures. Uda (1961), Schaefer (1961), Broadhead and Barrett (1964), Blackburn (1965), Laevastu and Rosa (1970) and Williams (1970) have all noted that yellowfin and skipjack tunas, particularly, are found in commercial quantities in tropical areas bounded on the north and south (northern hemisphere) by the 68°F (20°C) and 63°F (17°C) isotherms for the two species, respectively. The upper limit of the tuna's temperature range has been described by most of the aforementioned researchers to be between 84°F (28.9°C) and 86°F (30°C). Throughout the year in the eastern Pacific, the 68°F (20°C) isotherms reach the ocean surface along the southern boundary of the California current off Baja, California and along the cold side of the equatorial ocean front near the equator. Surface temperatures greater than 85°F (29.4°C) are found occasionally off southern Mexico during the spring and summer months.

During the past four years tropical tuna fishermen have recorded and transmitted to the Southwest Fisheries Center (SWFC), National Marine Fisheries Service, La Jolla, California, surface and subsurface marine obser-

[1] Ann. Rep. Inter-Amer. Trop. Tuna Comm., 1974. The Fishery in 1974; pp. 21-25. (in English and Spanish).

vations from the fishing grounds in the eastern tropical Pacific. In a joint research project the Inter-American Tropical Tuna Commission (IATTC) and the SWFC have been evaluating statistical relationships between tuna catch and concomitant ocean properties. The three dimensional thermal structure, down through the thermocline, over the tropical fishing grounds is closely related to the success in purse seining for yellowfin and skipjack. Nearly 86% of all successful purse seine sets in 1974 occurred in water with surface temperatures between 79°F and 84°F. Less than 10% of the sets were made where temperatures were less than 79°F; and only 4% of the sets were made in very warm water of 85°F or greater. Based on over 4,000 tuna boat bathythermograph (XBT)observations the distribution of successful sets on tuna, as a function of sea surface temperature (Figure 1), was similar in all areas and fishing seasons from 1971 through 1974 in the eastern tropical Pacific.

Each year the IATTC publishes in its annual report the distributions of the total yellowfin and skipjack catches by 1° guadrangles. Figure 2 shows the distribution of yellowfin catch captured by the international tuna fleet in 1974. In addition, the composite positions of the 68°F and 79°F isotherms have been superimposed on the yellowfin catch in Figure 2. The position of each isotherm represents the annual, composited position determined from surface temperatures published in Fishing Information (Miller, 1974) and observed by tuna boats and commercial ships. In finding the composite location of each isotherm maximum weight was given to temperatures observed by tuna boats in areas of most active fishing. After March 18, 1974, when yellowfin fishing became regulated east of 120°W, the tuna fleet expanded its fishing westward to 150°W. The positions of the 79°F isotherms west of 120°W for example, were based primarily on data from April through November 1974. Figure 2 shows that the 79°F isotherms enveloped those areas where most of the yellowfin were captured in 1974. The areas from 5°N to 15°N between 115°W and 120°W and to the west of 145°W all had surface temperatures greater than 79°F; but these were areas of limited fishing effort. In other years studied (1971-1973) similar horizontal relationships between annual yellowfin catch and the 79°F isotherms were found. However, the distributions of catch and temperature were different, especially south of 10°N. Surface temperatures below 79°F in the

Gulf of Panama and westward from the Costa Rica (upwelling) dome (near 8°N, 92°W, in 1974) were associated with vertical ocean mixing and upwelling.

Along the southwest coast of Baja, California the 68°F isotherm marked the northern limit of yellowfin catches. Along the coast of southern Ecuador and Peru temperatures remained below 68°F. During 1974 the anchoveta fishery was recovering from a record low catch of 1.96 million (metric) tons in 1973 following the devastating 1972-73 El Niño. Some yellowfin tuna were captured in the Gulf of Guayaquil during periods when temperatures were above 68°F.

During all of 1974 surface temperatures were 2°F to 6°F below normal along the equator and in the Peru Current. Figure 3 shows the composited patterns of negative temperature anomalies of 2°F and greater. The annual temperature anomaly patterns in Figure 3 were obtained by graphically compositing the anomaly charts published monthly in Fishing Information (Miller, 1974). Other areas where temperatures remained below normal during 1974 were southwest of Baja and along 10°N around 115°W. As indicated in Figure 2, fishing in these areas was not good in 1974.

A comparison of Figures 2 and 3 reveals that the most productive fishing areas in 1974 had surface temperatures near or slightly above normal. One exception was off Costa Rica where strong northeast trades increased ocean mixing and kept surface temperatures below normal during the most active fishing period. Along the coast of Peru temperatures were also low, but this condition in 1974 helped to restore the anchoveta fishery. In early 1974 high rates of anchoveta catch were reported during a very restricted fishing period.

Past studies have not uncovered any significant relationships between sea surface temperatures and abundance of yellowfin tuna in selected areas of the eastern tropical Pacific. However, sea surface temperatures and their deviations from the long term means (anomalies) are good indicators of large scale ocean changes. Apparently the most active tropical tuna fishery is found where seasonal temperatures remain in the 79°F to 84°F range. The largest year-to-year changes in temperature occur on the periphery of the traditional fishing grounds and occasionally inshore along Central America. Therefore, monitoring ocean surface temperatures can provide useful information about tropical ocean conditions, especially just before and after the beginning of the fishing season. Conventional surface and subsurface (XBT) marine data supplemented by the high resolution (thermal infrared) satellite temperature data (Stevenson and Miller, 1975) now provides an improved data base for monitoring the ocean thermal structure in the mixed layer.

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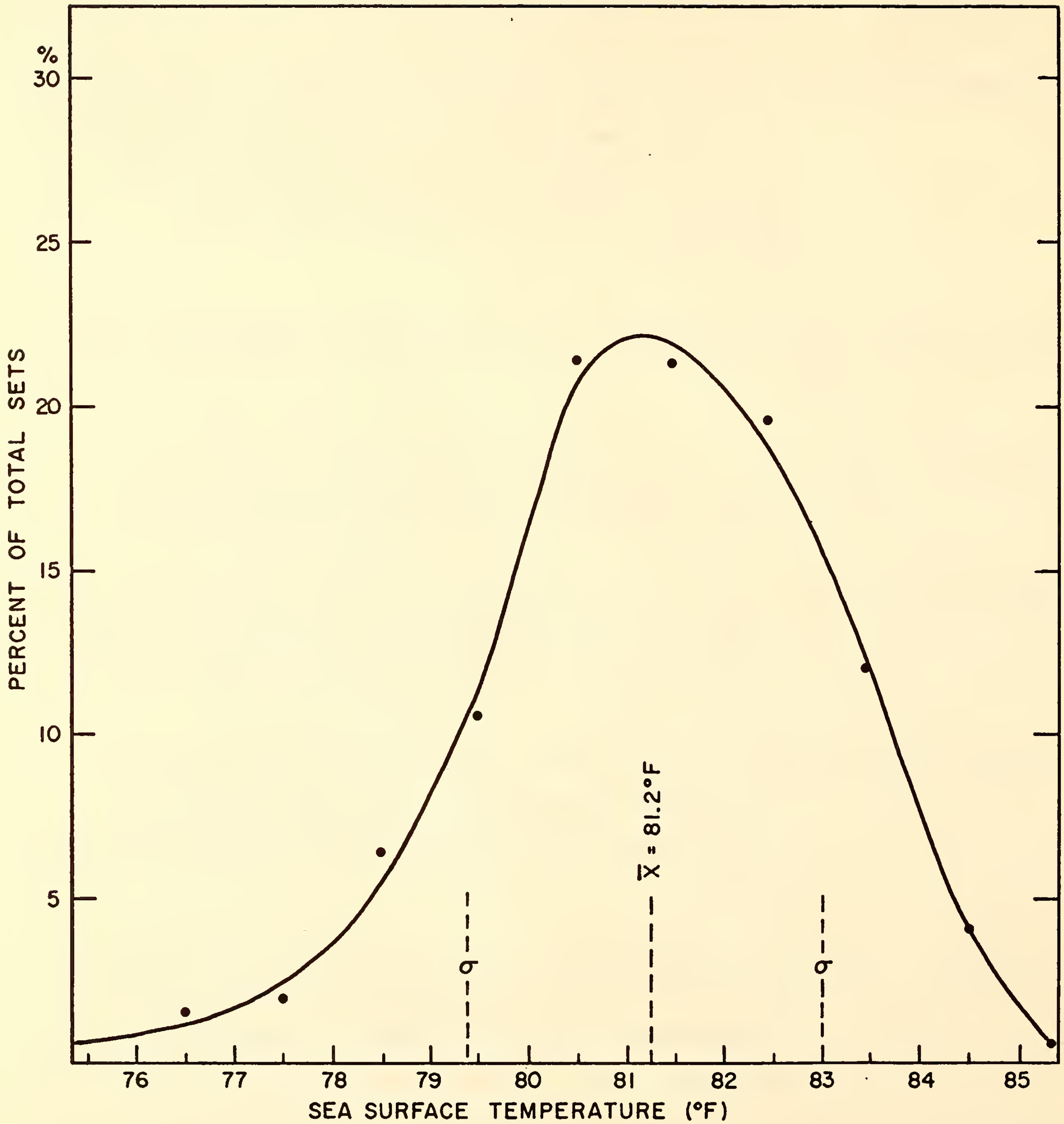

Figure 9.1 Percentage distribution of the total successful purse seine sets on yellowfin and skipjack tuna as a function of sea surface temperature observed by tuna boats in the fishing grounds of the eastern tropical Pacific from 1971 to 1974. The mean and standard deviation values are shown.

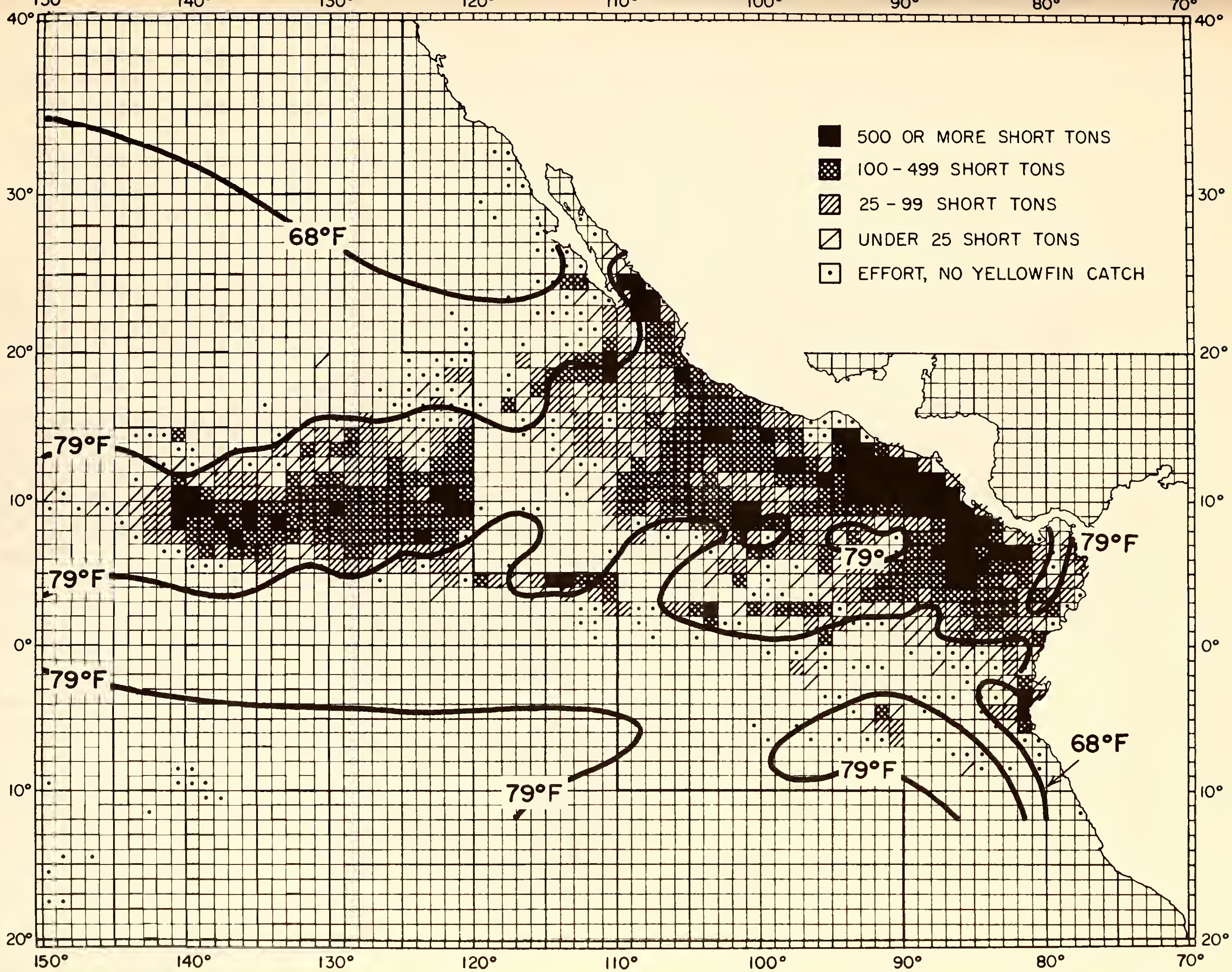

Figure 9.2 Catches of yellowfin in the eastern Pacific Ocean in 1974 by 1-degree quadrangles from the Inter-American Tropical Tuna Commission Annual Report for 1974. Annual, composited positions of the 68°F (20°C) and 79°F (26.1°C) isotherms, based on monthly sea surface temperature charts (1974), have been superimposed on the catch distribution.

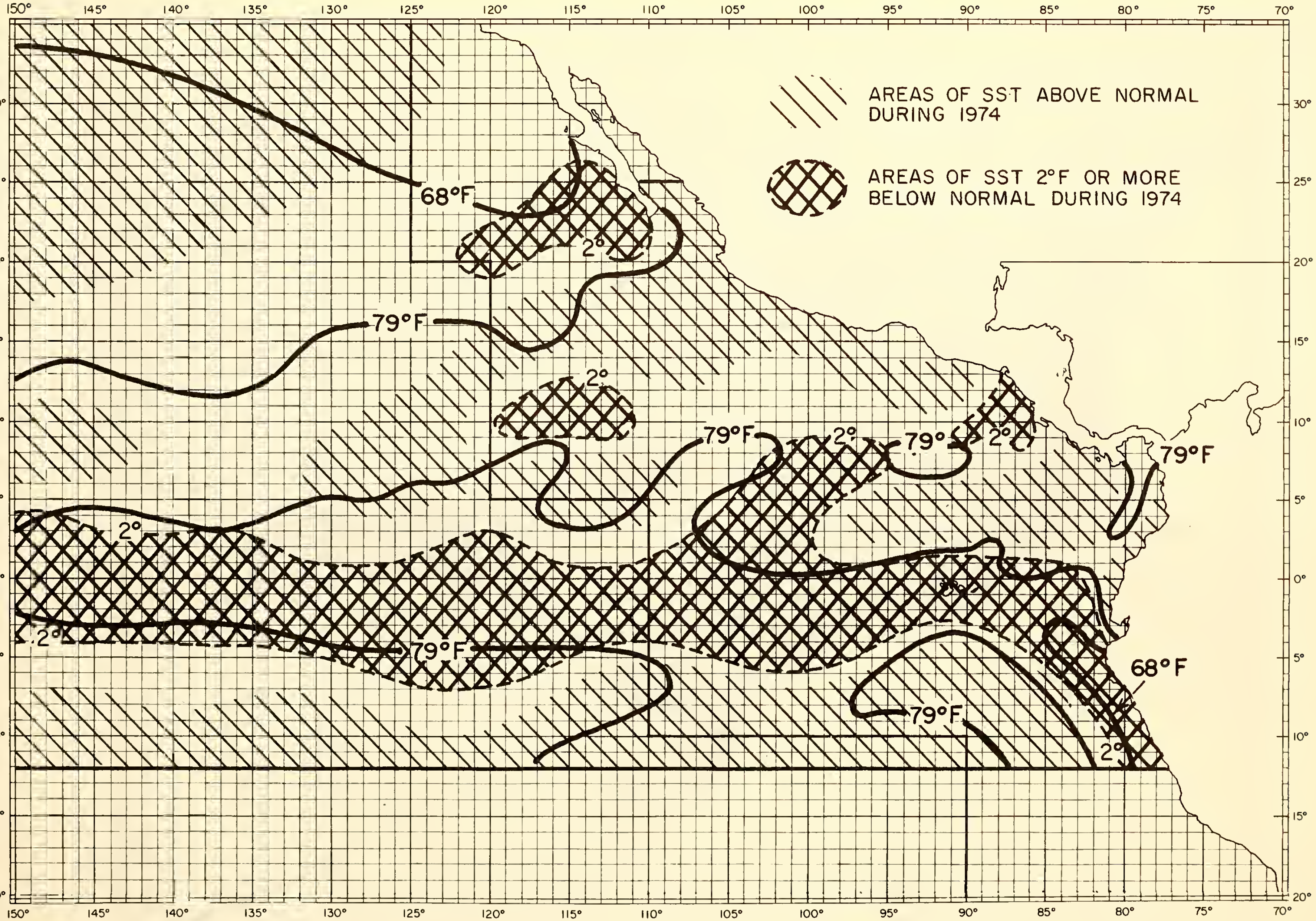

Figure 9.3 An annual, composited sea surface temperature anomaly pattern which persisted during 1974. Monthly temperature anomaly charts were graphically combined to form the annual composite. The positions of the 68°F and 79°F isotherms in 1974, as described in Figure 2, are shown also.

TEMPERATURE AND DISSOLVED OXYGEN DEFINE SKIPJACK TUNA HABITAT

By

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ABSTRACT

Neill, Gooding and others at the National Marine Fisheries Service Honolulu Laboratory have measured a variety of physiological parameters of skipjack tuna. The factors which most obviously tend to limit the distribution of these fish are: (1) the lower lethal temperature, approximately 14° to 18° C depending upon prior conditioning; (2) the lower lethal dissolved oxygen concentration, 4 to 5 ppm. or 2.8 to 3.5 ml/liter; and (3) an upper temperature bound which varies with size and metabolic rate of the fish.

According to Neill, a normally active skipjack tuna, whose metabolic activity requires some 3 mg oxygen/gram/hour, undergoes thermal stress if the ambient water temperature exceeds 33°C for fish smaller than 1 kg, and lesser temperatures for larger fish, such as 20°C for a 12 kg animal. If the water is too warm, skipjack tuna must either reduce their activity, or risk overheating of muscle tissue, because they conserve body heat with marked efficiency.

Skipjack tuna should therefore inhabit waters with oxygen concentration in excess of 3.5 ml/liter, and temperatures between about 18°C and the upper bound appropriate for their size and activity. Throughout the equatorial Pacific Ocean, water in the lower portion of this temperature range is deficient in oxygen, and the maximum habitat depth is set by the oxygen requirement. At higher latitudes, the water at the cold limit has enough oxygen, and low temperature is the limiting factor.

Skipjack tuna can exceed their thermal limits for short periods of time, because the time constant (the e-folding response time for a step change in water temperature) for skipjack tuna muscle temperature ranges between 30 minutes and an hour. That is, skipjack tuna can forage for some time in water which is clearly too warm, provided that cool oxygenated water is available immediately below; similarly, they could move into water which is oxygenated but too cold for long-term comfort, as long as there is water overhead in which to warm up afterward.

Clearly the normal habitat of all but the smallest skipjack tuna is the upper thermocline, for most of the year, throughout most of their range. In much of the eastern tropical Pacific, however, water

with at least 3.5 ml/liter of oxygen is warmer than medium and large skipjack tuna can tolerate; some 300 km off Mexico's west coast, the minimum temperature of adequately oxygenated water may exceed 26°C, which would stress fish larger than 4 kg. This warm, low oxygen water is found between 10° and 15°N, 105° to 120°W, approximately. Fish which require water cooler than 24°C (those larger than 6.5 kg) should in addition be excluded from coastal waters between Tehuantepec and Cape Corrientes.

The location and extent of these "forbidden" areas probably varies with season, and from year to year, depending upon mixing and advection--and thus upon winds and currents. These variations should be reflected in the geographic distributions of skipjack tuna of various sizes caught off western Mexico.

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El Niño, Anomalous Equatorial Pacific Conditions and their Prediction

by

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ABSTRACT

A technique for monitoring and predicting the El Niño-type activity and its antithesis has been developed over the past year and a half; and for the last nine months a real-time monitoring, prediction, and verification program has been conducted to test and improve this technique. The technique uses the trends in plots of various length running mean values (e.g., 1-, 3-, 6-, 12-month running means) of Southern Oscillation indices for monitoring the developmental stages and predicting anomalous equatorial Pacific activity and El Niño. A brief discussion of the technique and its application is included.

A chronological account concerning the author's prediction for El Niño-type activity in 1975 and how it led to the El Niño Watch project is presented. Based on information from the first El Niño Watch cruise and the UNESCO oceanographic representative in Guayaquil, Ecuador, it appears that the forecast for a weak El Niño occurrence off the South American west coast has verified. This test result on the forecasting technique is significant in that: (1) it not only predicted the event occurrence but also its intensity; (2) it was issued sufficiently in advance to allow preparation for the subsequent El Niño Watch project and its cruises to study the onset of an El Niño in the early stages of its development; (3) it predicted an event to occur three years after the onset of the strong 1972 El Niño, a situation which would have been considered quite unlikely from the general statistics on past occurrences.

1. Introduction

Earlier studies showed there was a relatively close relationship between phases of the Southern Oscillation and the anomalous extremes in rainfall over the central and western equatorial Pacific (Quinn and Burt, 1970, 1972). In the 1972 paper, monthly mean sea level atmospheric pressure differences between Easter Island and Darwin, Australia were used to represent circulation fluctuations; and, simplified approaches for determining the occurrence or nonoccurrence of anomalous equatorial Pacific rainfall, based on the graphic trend of the pressure difference, were suggested. Recently, this Southern Oscillation index and additional indices have been treated so as to emphasize the interannual changes and used in an improved method for monitoring and predicting the El Niño-type activity and its antithesis (Quinn, 1974, 1975).

This article is devoted to a brief background discussion of the forecasting method, a chronological account of the recent forecast that led to the El Niño Watch Project, findings through March 1975 off the coasts of southern Ecuador and Peru, and some conclusions concerning the forecasting technique.

To clarify the use of certain terms in this discussion, the following definitions are provided:

a. The Southern Oscillation, a term introduced by Walker (1923, 1924), is loosely defined as a fluctuation in the intensity of the intertropical general atmospheric and hydrospheric circulation over the Indo-Pacific region (Berlage, 1961). Troup (1965) describes it as an exchange of air between Eastern and Western Hemispheres, principally in tropical and subtropical latitudes. This exchange of air is associated with variations in a mean toroidal circulation driven by temperature differences between the two areas. For simplicity, Troup (1965) considers there is a single drift of most importance in the upper troposphere and that this flow is from the area of the Indonesian equatorial low across the Pacific to its central and eastern regions. It is compensated by a return flow near the surface from the eastern Pacific to the region of the low. There is descent in this circulation over the central and eastern Pacific, ascent in the vicinity of the equatorial low and a toroidal circulation in the vertical-zonal plane is maintained. The pressure changes which result in the index variations discussed in this paper are a consequence of variations in this circulation. Quinn (1971) contains a capsulized discussion of this large-scale feature.

b. The term El Niño-type development, situation, or condition is occasionally used in this proposal for convenience. This broad connotation represents the occurrence of anomalously warm sea surface temperatures in the equatorial Pacific along with abnormally heavy precipitation, and at times a disastrous invasion of anomalously warm surface waters along the coast of Peru (the actual El Niño occurrence). This type of development is brought about by relaxation from a prolonged period of strong southeast trades (represented by high Southern Oscillation indices) to a period of unusually weak southeast trades (represented by low Southern Oscillation indices). The intensity of this relaxation and its timing appear to determine whether or not a strong El Niño occurs along the Peruvian coast (Quinn, 1974). By using this broader term, we avoid getting into hassles over what is and what is not an El Niño, and can then account for those events that evolve in a similar manner but vary in timing and intensity.

c. The El Niño antithesis, or as some call it the anti-El Niño, refers to the contrasting situation when a prolonged strong southeast trade system prevails. In this case, there are strong upwelling, anomalously low sea surface temperatures and abnormally low amounts of rainfall over the equatorial Pacific (Quinn and Burt, 1972; Quinn, 1975), with strong coastal upwelling, low sea surface temperatures and high primary productivity off the coast of Peru.

2. Prediction of El Niño-type activity

The monitoring and prediction technique of Quinn (1974), as briefly discussed here, pertains to the El Niño-type development which involves relaxation from a prolonged strong southeast trade system to a weak one. This results in a slackening or cessation of equatorial upwelling, a rise in sea surface temperatures and abnormally large amounts of rainfall over the equatorial Pacific; and, in the strong cases, El Niño invasions.

Considering the 12-month running mean plot for the Easter-Darwin index (see Figure 1), in the case of unusually large developments the buildup time from a prior trough to the pre-El Niño peak is quite variable and generally takes place over a period ranging from 16-30 months. However, the drop from this peak to the subsequent trough in such cases usually takes place over a 15 to 21-month period. Of course, smaller developments may show a shorter time span for peak buildup and also shorter relaxation time in the drop to a subsequent trough. The time involved in relaxation from peak to trough, determines how far in advance of event occurrence a forecast can be issued. Here we consider the larger developments.

In forecast applications, when a prolonged steep rise in the 12-month running mean plot is noted (for either the Easter-Darwin or Juan Fernandez-Darwin index), the possibility of a pre-event peak development must be considered. If this steep rise continues and the plot approaches the 12 mb level, some equatorial Pacific activity can be expected and possibly a weak El Niño. This alerts one to a detailed study of the situation with additional indices (e.g., Figure 2), shorter period running mean plots (e.g., Figure 3), and similar plots for index components (e.g., Figure 4). If the 12-month running mean plot continues to rise and reaches or exceeds 13 mb, extensive abnormally heavy equatorial rainfall can be expected and the likelihood of a significant El Niño occurrence becomes apparent. When an index peak in excess of 13 mb is reached, and a downward trend sets in early in a particular year, one can expect the El Niño invasion between January and March of the following year if the relaxation continues. The heavy central and western equatorial Pacific precipitation usually starts a few months after the El Niño sets in but this may not always be the case. The 6-month lead time required for a 12-month running mean value allows about a 3-6 month forecast for El Nino using this approach; however, speculative outlooks

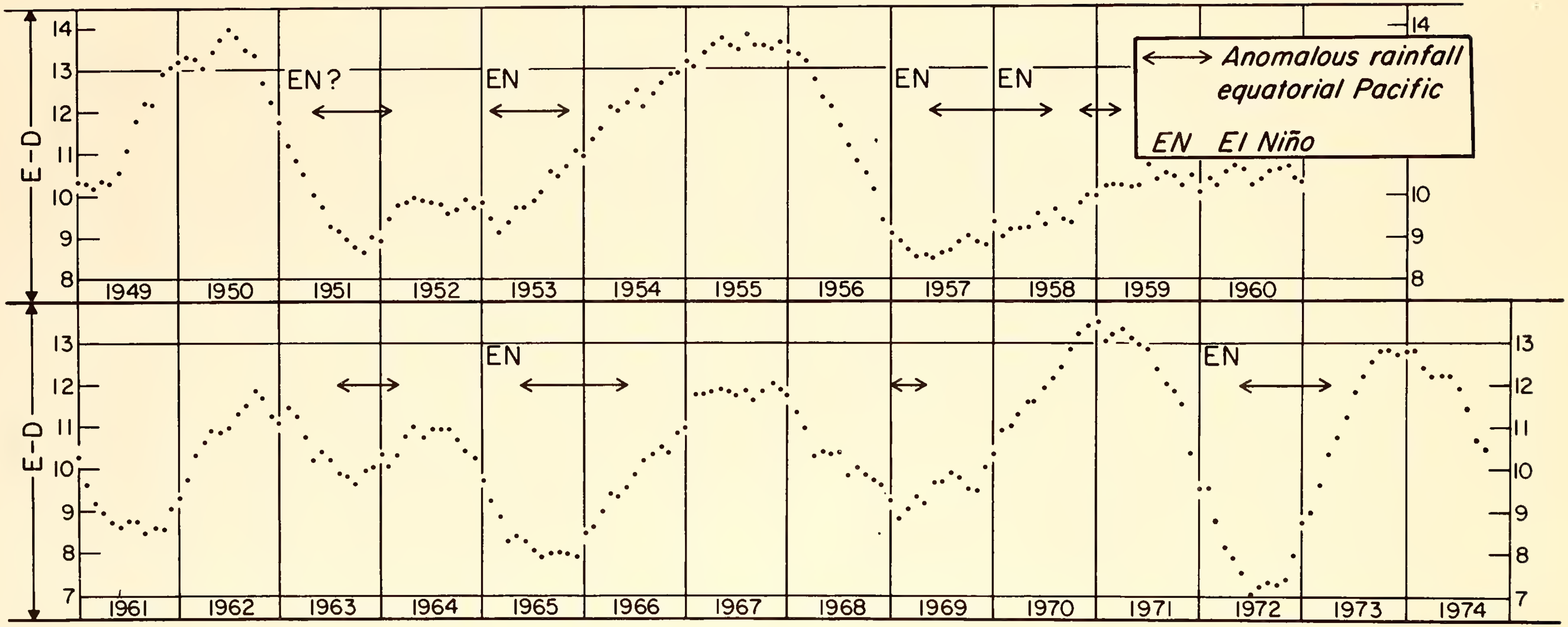

Figure 1. The 12-month running means (points plotted at middle of the 12 months) of the difference in sea level atmospheric pressure (mb) between Easter Island and Darwin, Australia for 1949-74. Periods of El Niño and abnormally heavy central and western equatorial Pacific rainfall are indicated.

Figure 2. Comparison of the 12-month running means (points plotted at the middle of the 12 months) for the difference in sea level atmospheric pressure (mb) between Juan Fernandez Island and Darwin, Australia (JF-D), between Easter Island and Darwin (E-D), between Totegegie (Gambier Islands) and Darwin (T-D), and between Rapa (Austral Islands) and Darwin (R-D) for 1961-74.

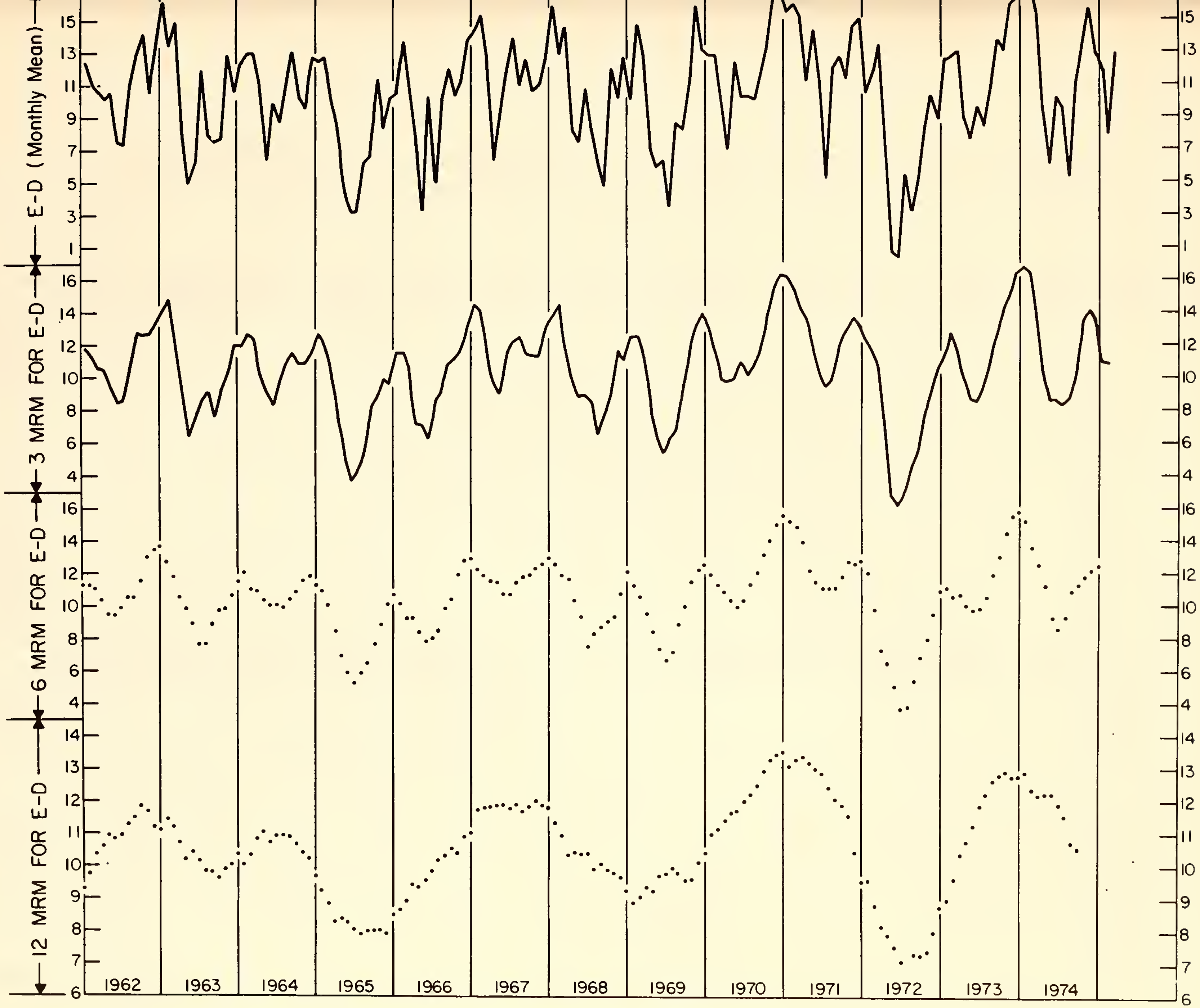

Figure 3. Monthly means, 3-month running means, 6-month running means and 12-month running means of the difference in sea level atmospheric pressure (mb) between Easter Island and Darwin, Australia for 1962-74. (Points are plotted at the middle of the involved periods.)

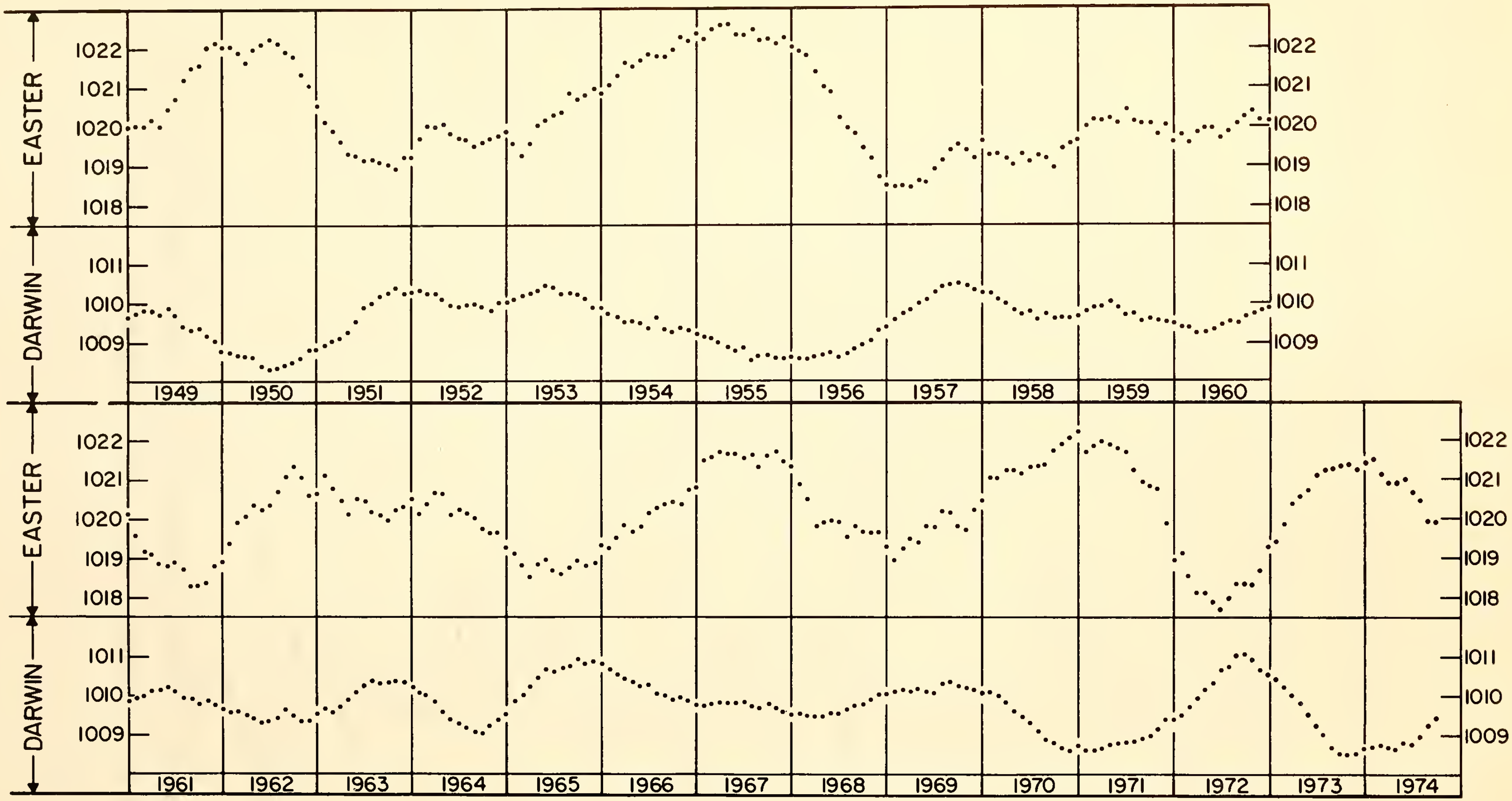

Figure 4. The 12-month running means (points plotted at the middle of the 12 months) of sea level atmospheric pressure (mb) for Easter Island and Darwin, Australia for 1949-74.

can at times be issued 12 or more months prior to an event. When monitoring the situation as it sets in, the shorter period running means and monthly mean sea surface temperature analyses for the tropical Pacific (U.S. Department of Commerce, 1972-75) are particularly useful. After the 12-month running mean trough has occurred and a persistent, relatively steep rise in the running mean trend again prevails, one can expect a return to the meteorological and oceanographic conditions characteristic of a strong southeast trade condition.

The index component inputs (see Figure 4) become important considerations when an apparent pre-event peak is developing. If the contribution to a high 12-month running mean peak of the index is relatively small from the Darwin component but relatively large from the Easter component (very strong South Pacific subtropical high) stronger activity would be favored in the eastern equatorial Pacific on relaxation. If the input is relatively large from the Darwin component (unusually deep Indonesian equatorial low) but only moderately large from the Easter component, stronger activity in the western equatorial Pacific would be favored on relaxation.

The situation leading up to the strong 1972 El Nino was quite unusual. The irregular interannual fluctuation (Southern Oscillation) was large and in this case had a period of about three years. Also, the interannual peak was in phase with the regular annual peak (the regular annual fluctuation in the index shows up clearly in the 6-month running mean plot of Figure 3, with its peak near the beginning of each year and its trough near the middle of the year), giving an exceptionally high 6-month running mean peak at the beginning of 1971. Likewise, in this case (Southern Oscillation of about a three-year period) an exceptionally deep trough occurred in the middle of the following year (1972) when the second annual trough (following the high early 1971 peak) was in phase with the longer period interannual trough (see Figure 3). Over a period of 18 months on the 6-month running mean plot (for the Easter-Darwin index) there was an excursion of 12 mb (between the early 1971 peak and the mid-1972 trough); and, over this same period there was a 14 mb excursion in the 3-month running mean plot (see Figure 3). This represents an extreme relaxation in the southeast trade system. Since the average annual fluctuation in the Easter-Darwin 6-month running mean is about 4 mb and in the 3-month running mean is about 6 mb, it indicates how large the interannual contribution can be and how important the Southern Oscillation is to the development of anomalous equatorial Pacific activity and El Niño. If the two index fluctuations (the regular annual and the irregular interannual) are out of phase, they tend to counteract one another and the 6-month running mean plot shows stunted peaks and troughs. In cases where peaks are in phase and troughs are out of phase, developments are weak. It is essential that the troughs of the two fluctuations be in phase to get significant developments [Figure 5 is taken from Quinn (1975) and shows schematically the 6-month running mean trend associated with the 1972 development].

3. The El Niño antithesis

It appeared that this monitoring and prediction technique could be applied more generally in support of fishery environments affected by the

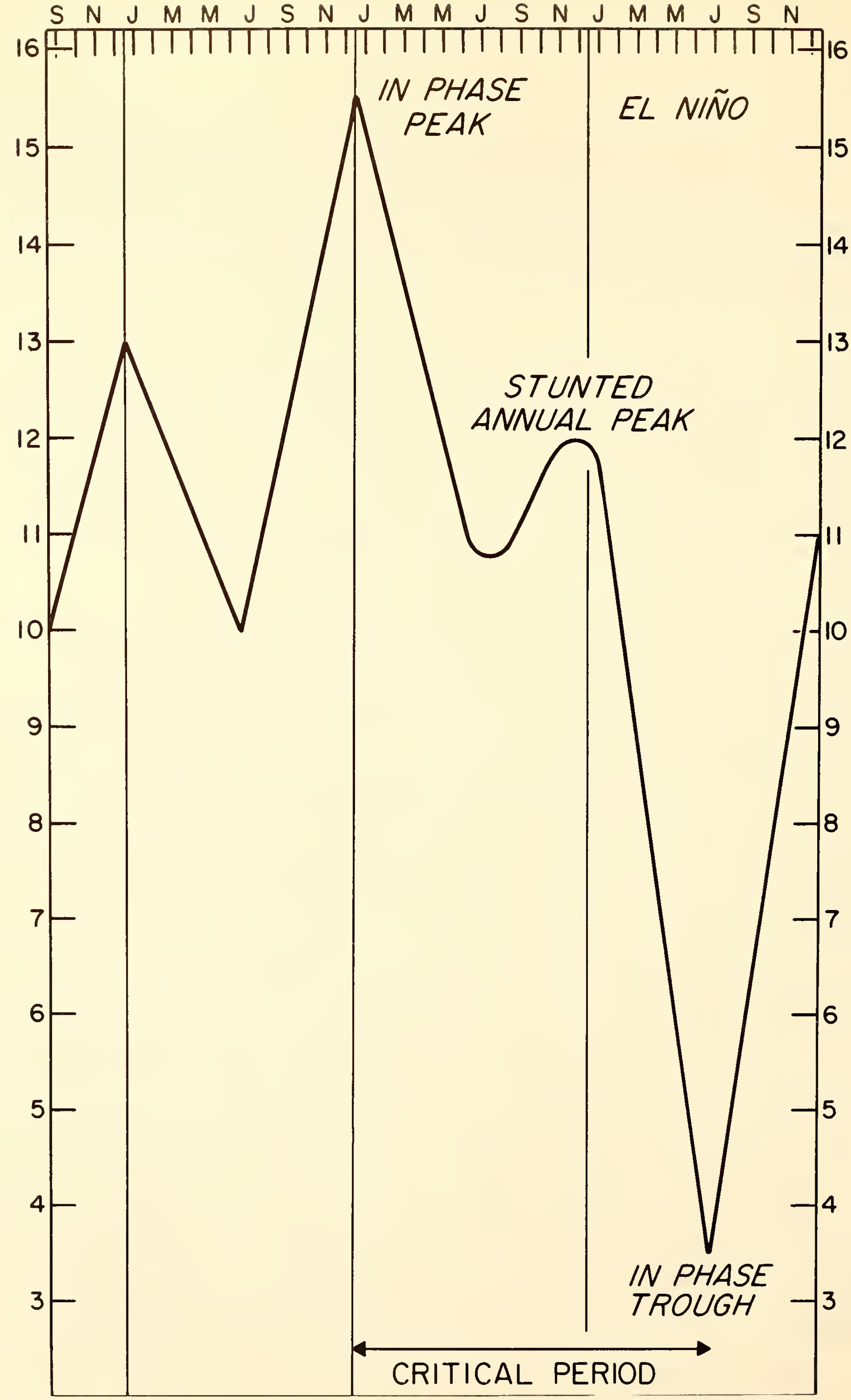

Figure 5. Schematic representation for the 6-month running mean trend of the Easter-Darwin atmospheric pressure difference (mb) relating to an exceptionally strong equatorial Pacific event and El Niño.

anomalous equatorial Pacific conditions (Quinn, 1975). Here reference is made to fishery zones which are significantly affected by variations in primary productivity [as a consequence of strengthening or slackening in upwelling activity (in response to a strengthening or weakening of the southeast trade system), in the equatorial Pacific and off the coast of Peru] or by the sizable associated variations in surface and near-surface sea temperatures. The high degree of consistency between index features and equatorial meteorological (see Figure 6) and oceanographic activity tends to justify the use of the running mean trends of the indices for this more generalized monitoring and prediction purpose.

The possibility of forecasting this opposite extreme, using monthly means of the indices, was first discussed in Quinn and Burt (1972). It was noted at that time that the persistent high Easter-Darwin pressure differences favored extensive unusually dry equatorial Pacific conditions. Several examples were cited where this opposite extreme prevailed over periods 18 months to three years in length.

Here we consider monitoring and predicting physical conditions that favor primary productivity in the affected oceanic zones, by following trends in the running mean plots of the indices. When the 12-month running mean plot rises steeply for many months and reaches and remains at high levels, it indicates a strengthening and strong southeast trade system prevails and that a return to widespread upwelling and anomalously low sea surface temperatures is occurring over the equatorial Pacific and along the Peruvian coast. The height and breadth of the 12-month running mean peaks determine the intensity and time span respectively of developments which favor this widespread upwelling condition.

Perhaps persistence-type forecasts would be more appropriate for developments of this nature, since we will often be dealing with peaks of lesser intensity than the pre-El Niño variety and also since such activity may often persist for periods in the 18 month to three-year range. The 12-month running means of the Southern Oscillation indices and the monthly sea surface temperature analyses (U.S. Department of Commerce, 1972-75) should be excellent tools for monitoring such developments and issuing persistence-type forecasts. An approaching deep 12-month running mean trough will signal the end to conditions of this nature.

4. Outlook for weak 1975 El Niño and the El Niño Watch

The following is a chronological account concerning the prediction made for El Niño-type activity in 1975 which led to the "El Niño Watch Project," in order to give some idea of the capability of this technique for monitoring and predicting such conditions.

The first sign noted was the steep rise toward a pre-El Niño peak which became apparent in the trend of the 12-month running mean plot of the Easter-Darwin index when considering data available through 1973. Based on these data (at this time I was relying on library data sources which are usually about 8 months late), I gave a speculative outlook for El Niño-type activity in 1975 at the end of my presentation to the ONR-NSF NORPAX review

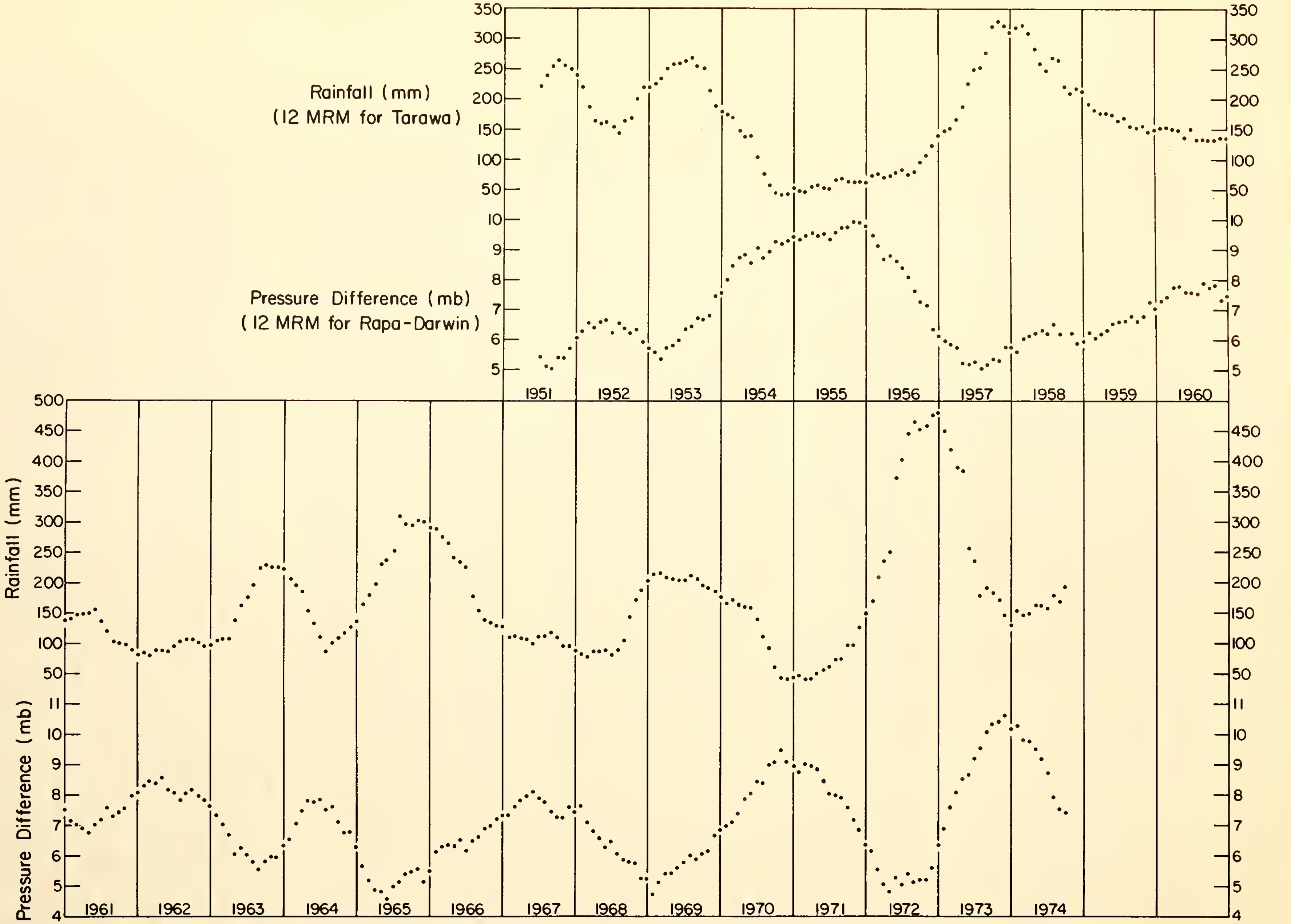

Figure 6. Comparison of 12-month running mean values (points plotted at middle of 12 months) of rainfall (mm) for Tarawa (Gilbert Islands) to 12-month running means of the difference in sea level atmospheric pressure (mb) between Rapa (Austral Islands) and Darwin, Australia for 1951-74.

group at Monterey in August, 1974. The outlook was speculative since the valid time for the forecast was over a year later than the data on which it was based; also, the peak in the running mean trend had not yet been reached so I could not provide an estimate of the intensity of the development.

A firm outlook for El Niño-type conditions in 1975 was prepared in late September, 1974 based on data obtained through August, 1974. This forecast was issued during a presentation at the Eastern Pacific Oceanic Conference (EPOC) on 2 October 1974 at Lake Arrowhead, California. It was this forecast which was published in the fall issues of the "NORPAX Highlights" and the "CUEA Notes." It called for an El Niño-typc development with a week El Niño occurrence in early 1975. The Easter-Darwin 12-month running mean peak in this case was a little less than 13 mb and this was the basis for the forecast for a weak El Niño. The stronger El Niños have followed relaxation from peaks in excess of 13 mb.

Later, at the EPOC meeting, a group including J. Bjerknes, K. Wyrtki, G. Flitner, W. Patzert and the author met to consider the possibility of taking advantage of this forecast to study a development of this nature in its formative stage; and, although the outlook called for a weak El Niño, it was generally agreed that it might be several years at least before another such opportunity for study might rise.

Several weeks later, Dr. Wyrtki submitted a NORPAX proposal to activate the El Niño Watch project. He was Principal Investigator and the author, W. Patzert and E. Stroup were co-Principal Investigators. It was generally agreed that if the outlook remained favorable for the weak El Niño and NSF and ONR agreed on support of the project, 2 cruises over the area of interest west of Peru and Ecuador would be conducted between February and April, 1975. The go-decision was to be made after a 12 December meeting to consider last minute indications and preparations.

On 12 December 1974 the author presented a detailed briefing using running means of several different lengths and several different indices, all of which indicated no change in the forecast for a weak El Niño. Dr. Collins of NSF, Dr. Stevenson of ONR, Cdr. Summy and other members of his "Ship Rider" project, the El Niño Watch group, and other interested parties attended this meeting; and the "go" decision for the cruises was made by Dr. Wyrtki, with the concurrence of the attendees. The first cruise of the project was scheduled to leave San Diego in early February, 1975.

5. Conditions off Ecuadorian and Peruvian coasts February - March, 1975

The research vessel, Moana Wave, of the University of Hawaii has just completed the first cruise of the El Niño Watch project, and Drs. Wyrtki and Patzert report that El Niño conditions have developed off Peru and Ecuador in February and March, 1975. A massive transgression of low salinity water was observed across the equator just east of the Galapagos Islands; and, a thin layer of warm water with a salinity of less than 33‰ has advanced to 4°S.

The area off Ecuador is also covered with warm water of low salinity (less than 34‰). They further report that weak upwelling is still present along the coast of northern Peru to the south of Punta Parinas (4°S), but no cool water is advected northwest from this upwelling area as in normal years. Changes in subsurface layers that are more striking than the changes near the sea surface were noted. The 15°C isothermal layer is depressed along the equater to over 120 m depth, and in some spots to over 140 m depth, while in normal years it barely reaches a depth of 100 m. They state that this indicates a very strong flow of the equatorial undercurrent. The 15°C isothermal layer is also depressed along the coast of Ecuador and Peru to between 100 and 140 m depth, while normally it is near 50 m in depth.

Dr. R. L. Barber of the Duke University Marine Laboratory reports that the transgressing warm upper layer of water from the equatorial region southward had extremely low values of primary productivity (about 10% of the normal amount) and that they were much lower than those noted over this region in 1967 and 1968.

On this first cruise, Dr. Patzert of the Scripps Institution of Oceanography was the Chief Scientist. The scientific program on the ship consists of hydrographic, meteorological and biological measurements. Two radiosonde observations are being taken at standard times each cruise day by members of Cdr. Summy's U.S. Navy "Ship Rider" project. Vertical profiles of temperature, salinity, and oxygen are being taken at about 100 stations on each cruise, as well as samples for the determination of nutrient and phytoplankton concentrations. Primary productivity is measured and zooplankton tows are made to determine the abundance of biological activity. Data collection on board the ship is executed by technicians of the GEOSECS Group of Scripps Institution of Oceanography under the leadership of Dr. A. Bainbridge. There are also scientists, technicians and students from the University of Hawaii on board the ship, a scientist from the Duke University Marine Laboratory and visiting scientists from Peru and Ecuador.

Dr. D. B. Enfield, the UNESCO expert in Guayaquil, Ecuador, reported results from a cruise conducted by the Instituto Oceanographico de la Armada of Ecuador during the first half of March, 1975. It covered an area extending offshore 100 miles near 3°S, broadening out to 300 miles offshore at 1°N. In the south, sea surface temperatures of 26-27°C and salinities of 33-34‰ were noted; whereas, in the north values of 27-29°C and 31-33‰ were found. The salinities found during the March, 1975 cruise were comparable with those for February-March 1972 when the last big El Niño occurred. Enfield further reports that when the ship (1975 cruise) was between 1°N and 1°S from March 4 to 15, there were alternate periods of a few days each in which winds prevailed from the NE then the SE. In the former (NE periods), winds were stronger, more persistent and accompanied by higher seas than during the SE wind periods. On two occasions the NE winds were accompanied by squalls.

According to Enfield, anomalously large amounts of rain fell along the Ecuadorian coast during February and March, 1975, resulting in strong flooding. In January, rainfall at Guayaquil was near the 30 year normal at 222 mm. However, in February 487 mm of rain fell and in March 607 mm, as compared to normals of 237 mm and 264 mm respectively. For comparison, the months of greatest rainfall at Guayaquil during the 1972-73 El Niño were March, 1972 with 407 mm and March, 1973 with near 700 mm.

Enfield states in summary that the oceanographic and meteorological conditions in Ecuador during February and March, 1975 approach those at the onset of the 1972-73 El Niño; however, off Peru the intensity of positive temperature anomalies and the southward extent of low salinity water were considerably less in 1975 than at the onset of the 1972-73 El Niño. He goes on to say that perhaps the best historical analogue for strong (El Niño-type) climatological anomalies in Ecuador, in conjunction with weekly anomalous conditions to the south, is the 1969 event.

6. Further comments

The last remark by Enfield is interesting, in that the author also thought the 1975 event might be similar in intensity to the 1969 event off the coast of northwestern South America, when the 1974 forecast for a weak El Niño was made. It is also interesting that we had a weak event set in early in 1969, a strong event in early 1972, and what so far appears to be a weak event in early 1975. This near decadel span of cyclic activity in the generally irregular Southern Oscillation I have noted at other times over the past century. When it appears to be occurring, it may be an additionally useful consideration for predictions on El Niño-type activity.

The difference in these developments can be most clearly noted by referring to the index components (see Figure 4) and considering the large scale features. For the 1967 pre-event (1969 case) peak there was a fairly large Easter contribution but a small Darwin input; the result being a weak El Niño and moderately heavy anomalous rainfall over the central and western equatorial Pacific. For the 1970-71 pre-event (1972 case) peak there was a large contribution from both components; the result being a strong El Niño and strongly anomalous heavy rainfall over the central and western equatorial Pacific. For the 1973-74 pre-event (1975 case) peak there was a moderate Easter contribution (significantly less than in 1972) and a large Darwin input; and it was for this reason that the prediction called for a weak El Niño in early 1975.

A second El Niño Watch cruise by the Moana Wave will set out in mid-April, 1975 and repeat the pattern of the first cruise (covering the area from about 14°S to about 2°N between the South American West coast and 95°W longitude) with Dr. E. D. Stroup as the Chief Scientist. It will provide later information on the status of this ocean-atmosphere development.

7. Conclusions

As of this time, it appears that the formalized forecast for a weak El Niño in early 1975, which was prepared in late September, 1974 and issued October 2nd at the Eastern Pacific Oceanic Conference (as well as the more speculative outlook, based on data through 1973, given at Monterey in August, 1974) has verified. This forecast was particularly notable in that:

a. It not only predicted the event occurrence but also its intensity.

b. It was issued sufficiently in advance to allow preparation for the subsequent El Niño Watch project to study an event in its early stages of development.

c. This event occurred three years after the strong 1972 El Niño, a situation which would have been considered quite unlikely from the general statistics on past occurrences.

It was interesting to see that the trends in the 12-month running mean plot of the Easter-Darwin index (which represents variations in strength of the southeast trade system) agree, as would be expected, with Wyrtki's (1973) 12-month running mean trends for sea level difference across the north equatorial countercurrent (representing countercurrent transport) and his 12-month running means of sea surface temperature anomaly off the coast of Central America, as discussed in Quinn (1974).

A study of over 100 years of data indicates that although the anomalous equatorial Pacific developments show marked similarities, no two cases show exactly the same meteorological and oceanographic manifestations; and likewise, no two show exactly the same associated trends in running mean values of the indices or their components. This would be expected since these large scale fluctuations must be interrelated with developments in other parts of the atmosphere-hydrosphere system, and the timing and intensity of the various inputs could cause considerable variability in the evolutionary characteristics of the individual equatorial Pacific events. Namias (1973) noted certain relationships between the North Pacific atmospheric circulation and equatorial events. Also, a recent investigation of Ocean Station vessel N (30°N, 140°W) data (Dorman et al., 1974) indicated a correlation between certain large pressure anomalies and the more extreme anomalous equatorial Pacific developments. Later, from a plot of 12-month running mean values of the Ship N sea level atmospheric pressure figures, we found that significant interannual fluctuations (Southern Oscillation) were at times being reflected in the northeast Pacific subtropical high. This finding is in agreement with Troup's (1965) circulation model which represents the Southern Oscillation's exchange of air between the eastern and western hemispheres as a zonal-vertical toroidal circulation over the lower latitudes of the Indo-Pacific region. Additional study of interactions with Northern Hemispheric circulation features, as well as with other parts of the global tropics and subtropics, from both cause and effect standpoints, is highly desirable if we are to understand more completely the evolutionary nature of the unusual events discussed in this paper. Nevertheless, it appears that the Southern Oscillation, through its contribution to the strength of the southeast trade system, exerts considerable control over the anomalous equatorial Pacific meteorological and oceanographic developments, and the El Niño invasions off the coasts of southern Ecuador and Peru. Figure 6 documents the close correlation between Tarawa rainfall and the Rapa-Darwin index when the 12-month running mean values are used. Although Tarawa rainfall data were used here, Quinn and Burt (1970, 1972) show how closely the equatorial rainfall variations are interrelated at equatorial Pacific stations between 155°W and 165°E. It is interesting to note that the largest rainfall peaks in Figure 6 are associated with the two most severe developments of recent years (the 1957-58 and 1972-73 El Niños).

Acknowledgements

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COASTAL UPWELLING OFF WESTERN NORTH AMERICA, 1974

by

Andrew Bakun (PEG)

Coastal upwelling is a highly fluctuating process having important effects on fishery resources. Evidence of upwelling is often noted in sea surface temperature distributions, but because various processes modify sea temperature it is difficult to attach any quantitative measure to the upwelling involved. A different approach involves measuring the forces which actually drive the upwelling. In eastern boundary current regions, such as that off the west coast of North America, the primary driving force is the stress of the wind on the sea surface (Wooster and Reid, 1963). Water in the surface layer of the ocean is driven offshore by the action of the wind, requiring replacement at the coast by upwelling of deeper water. Bakun (1973) computed monthly indices of wind induced coastal upwelling using surface atmospheric pressure fields to estimate the sea surface stress field. Time series were produced at fifteen near-coastal intersections of a 3-degree computation grid (Figure 12.1). These series are routinely updated each month at Pacific Environmental Group for use by fishery scientists. Update values and anomalies for 1974 are presented in Tables 12.1 and 12.2.

A feature of these upwelling index series is a spatial distortion such that magnitudes in the vicinity of Southern California are artificially amplified relative to other locations (Bakun 1973). The indication in Table 12.1 of nearly equivalent upwelling intensity at 33N and 36N as at 39N during spring and summer is attributable to this

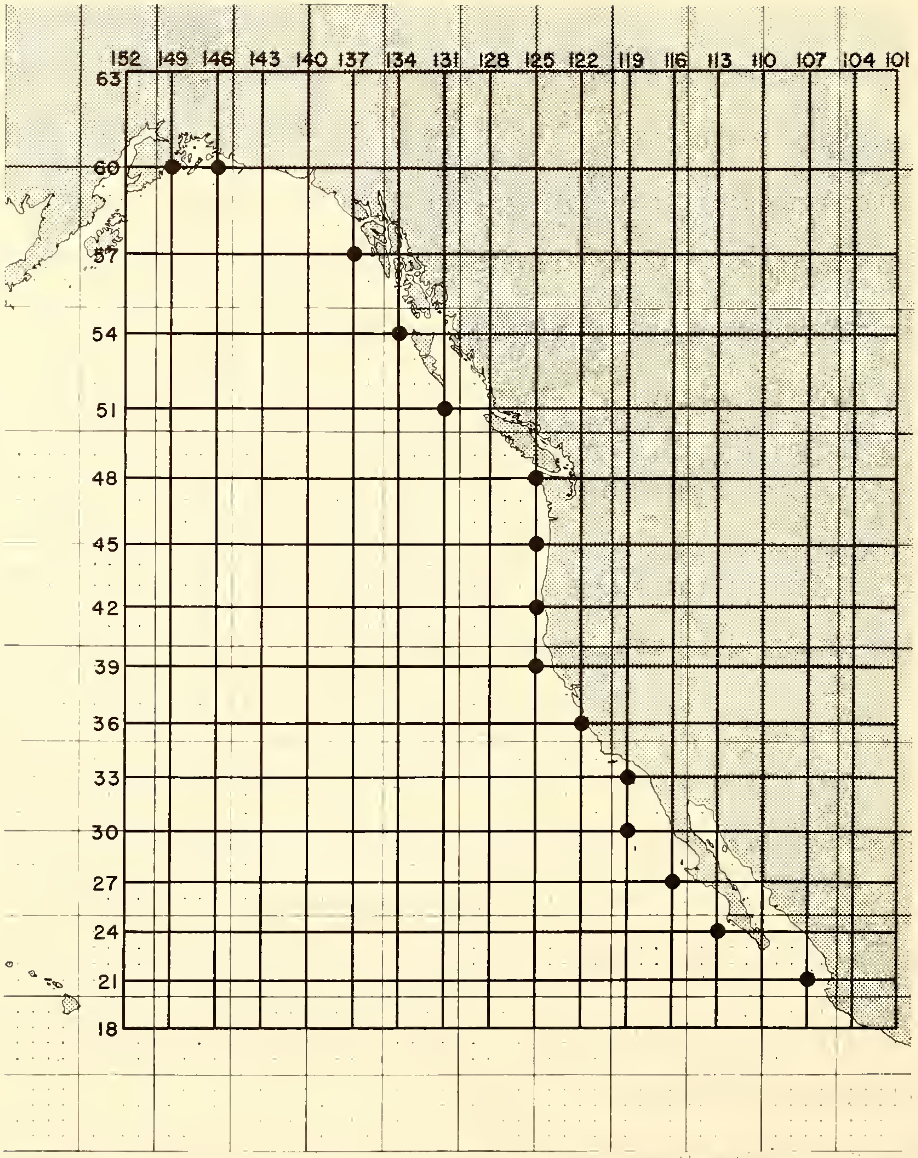

Figure 12.1 - Computation grid. Intersections at which upwelling indices are computed are marked with large dots.

Table 12.1 - Monthly coastal upwelling indices for 1974. Units are cubic meters per second per 100m length of coast. Negative values indicate onshore transport of surface waters and resultant downwelling.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	-142	-180	-62	-14	0	5	12	2	-11	-32	-41	-50
60N 146W	-202	-196	-79	-18	0	9	15	2	-20	-43	-60	-61
57N 137W	-129	-153	-55	-40	-4	-2	6	5	-28	-145	-138	-111
54N 134W	-8	-107	-10	-28	-13	-8	3	17	-13	-137	-111	-129
51N 131W	5	-37	-6	-9	-3	7	8	44	3	-35	-42	-62
48N 125W	-31	-46	-31	-3	12	38	19	37	4	-1	-50	-80
45N 125W	-36	-51	-37	2	26	80	36	72	16	6	-46	-75
42N 125W	-8	-17	-16	31	152	177	87	135	38	41	-22	-23
39N 125W	1	9	2	105	356	297	182	250	104	114	2	5
36N 122W	0	33	28	148	361	288	213	217	128	69	19	19
33N 119W	1	43	91	207	372	330	229	245	159	97	26	4
30N 119W	22	104	93	234	284	263	147	167	141	104	74	34
27N 116W	56	105	123	208	208	160	67	115	94	80	60	39
24N 113W	52	78	100	138	147	82	24	50	53	54	43	57
21N 107W	31	60	81	53	125	22	4	0	4	-1	5	37

Table 12.2 - Monthly coastal upwelling index anomalies for 1974 relative to the 20-yr (1948-67) mean value for each month and location. Units are cubic meters per second per 100 m length of coast.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	-3	-95	-17	-2	0	-1	6	-3	-8	-7	32	59
60N 146W	-22	-93	-31	-6	2	3	10	-1	-11	-9	33	68
57N 137W	82	-35	-4	-16	6	-2	5	11	1	-58	2	52
54N 134W	89	-39	18	-8	-3	-8	0	18	11	-55	-12	-38
51N 131W	69	-1	6	-4	-6	-8	-7	32	6	5	16	-4
48N 125W	59	2	-11	-3	-6	13	-15	15	0	38	38	20
45N 125W	58	-3	-21	-7	-8	32	-38	22	0	26	28	19
42N 125W	59	11	-19	-2	73	74	-44	44	3	41	20	34
39N 125W	13	0	-33	36	232	130	0	111	41	94	9	18
36N 122W	-11	-2	-51	28	158	50	15	34	34	20	7	12
33N 119W	-18	-5	-29	29	89	18	-2	33	22	20	5	-6
30N 119W	-35	27	-23	93	84	64	5	25	13	1	9	-19
27N 116W	-15	11	4	60	6	-34	-47	11	-16	-26	-14	-24
24N 113W	1	4	7	21	4	-47	-24	6	4	-15	-9	18
21N 107W	14	20	-16	-47	38	-16	0	-5	19	14	-3	29

distortion. The Cape Mendocino area near 39N latitude is actually the region of maximum upwelling intensity (Bakun, McLain, and Mayo, 1974). The major point to be made to users is that these series are designed to indicate temporal variations at each particular location rather than the spatial distribution at a particular time.

The information in Table 12.1 is presented in Figure 12.2 in terms of percentiles of the frequency distribution made up of the 29 values for each month and location within the 29-year (1946-74) series. In this presentation the spatial distortion is removed since no reference is made to absolute value but only to relative value among other yearly samples for the same month and location. Values above the median fall above the fiftieth percentile, etc.

The Northern Gulf of Alaska

The northern Gulf of Alaska is primarily an area of negative index values (Table 12.1) indicating convergence at the coast and resulting downwelling. Values in the early part of 1974 are below the median (Figure 12.2), i.e. more negative than normal, indicating more intense downwelling than normal. A possible result is that surface water conditions affected an unusually extensive area of the floor of the continental shelf. May, June and July show higher than normal upwelling index values. However, summer is characteristically a season of very little upwelling-downwelling activity in this region; the positive anomaly, even in July when it reaches the ninety-first percentile, is not very large in terms of quantity upwelled. August, September, and October are

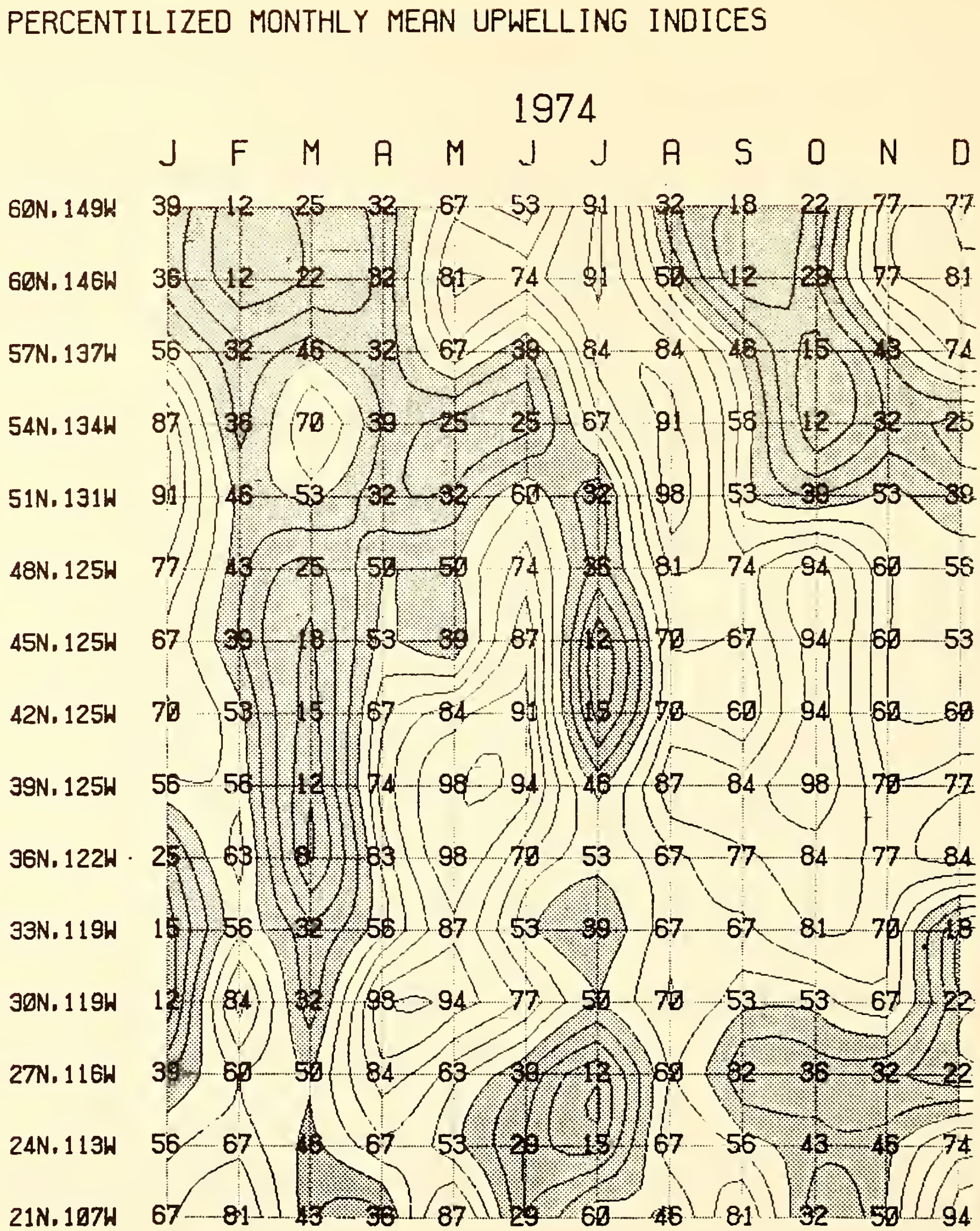

Figure 12.2 - Percentilized upwelling index values for 1974. Numbers indicate the percentile occupied by each monthly value within the frequency distribution of the 29 values for each respective month and location in the 29-year series, 1946-74. The contour interval is ten percentile units. Values below the median (fiftieth percentile) are shaded.

more negative than normal, indicating an early switch toward the winter downwelling condition. November and December show more relaxed downwelling than is usual for those months.

The Eastern Gulf of Alaska

During the early months of 1974 the upwelling indices at 54N and 51N latitudes show positive anomalies (i.e. less than normal downwelling) in January and March, and negative anomalies (more intense than normal downwelling) in February and April. At 51N an unusual positive value appears during January, indicating upwelling to have occurred on average. During May the downwelling continues to be more intense than normal. The seasonal transition to upwelling conditions occurs during June and July. August exhibits unusually intense upwelling at both locations. In fact the value at 51N is the highest August value observed at that location during the 29-year record. September has index values only slightly higher than normal and marks a transition from the upwelling in August to downwelling during the last quarter of the year. A very low value for October at 54N indicates an early return to winter conditions of intense downwelling.

Vancouver Island to central Oregon

The region from Vancouver Island to the central Oregon coast is a zone of transition between the Gulf of Alaska, which is dominated near the coast by winter downwelling, and the California Current region, where upwelling predominates. As in the region to the north, January of 1974 exhibits index values that are more positive than normal, indicating relaxed winter downwelling during that month. February is more nearly normal leading into abnormally intense downwelling in March. During April and May the situation is near normal with upwelling beginning to predominate off the Oregon coast during April and moving northward to the Washington coast during May. In June, upwelling is well established; however, during July, which is ordinarily the month of maximum upwelling in this area (Bakun, 1973) much lower than normal upwelling is indicated. The July index values are only about half the June and August values at both 45N and 48N latitude. August exhibits above average upwelling index values and September is nearly normal with upwelling intensity beginning to drop off according to the usual seasonal pattern. October has very high index values with some upwelling on average indicated at 45N. Normally, by October the winter downwelling situation is well established throughout the region. In November, although downwelling has been established, it remains somewhat less intense than normal. By December normal vigorous downwelling is indicated.

Cape Blanco to Point Conception

The core of the California Current coastal upwelling region lies along the stretch of coastline from Cape Blanco to Point Conception (Bakun, et al., 1974). The point of maximum intensity is normally in the Cape Mendocino - Point Arena area near 39N latitude. The major feature of the early months of 1974 is the group of extremely low indices for March indicating continued downwelling in the northern portion of the region (42N latitude) where normally upwelling has begun to predominate, and less intense than normal upwelling to the south (39N and 36N latitudes). By April, however, the index values are all above the median for that month, and the upwelling season is well established throughout the area. May and June show very strong positive anomalies, with the May values at 39N and 36N latitudes being the highest in the 29-year series. In July the intensity drops off, particularly in the north. By August the values are again well above the median, setting a pattern which continues through the remainder of the year. October is the most notable of these high anomaly months; the value at 39N latitude is the highest in the 29-year record for that month and location and the value at 42N is the second highest in its series. Although winter downwelling predominates at 42N during November and December it is less vigorous than normal. In summary, 1974 may be classed as a year of exceptionally strong upwelling within this primary coastal upwelling zone of the California Current region. This is in spite of a late start due to unusually weak upwelling during March.

Baja California

The Southern California Bight is dominated by a counter-clockwise eddy circulation (Reid, Roden, and Wylie, 1958) resulting in northward advection of warmer water along the coast. Although the winds in the area are favorable for upwelling, the offshore transport tends to be less than in the areas to the north and to the south (Nelson, 1974).

Upwelling undoubtably occurs, but it is likely that some of the offshore transport is balanced by horizontal flow along the coast.

The coast of Baja California is a secondary zone of coastal upwelling within the California Current region. Wind conditions favorable for upwelling occur generally throughout the year with a zone of maximum intensity along the coast from Punta Baja to Punta Eugenia, centered near 30N latitude (Bakun and Nelson, in press). The early months of 1974 are characterized by index values below normal or near normal for January, above normal for February and slightly below normal for March. Abnormally intense upwelling is indicated for April and May near 30N latitude. This feature extends along the entire Baja California coast but becomes less intense to the south. The higher than normal intensity appears to have continued during June at 30N latitude but falls below the norm at 27N and 24N latitudes. Less than normal intensity along the entire region is apparent in July; particularly low index values are reached at 27N and 24N latitudes. In August the upwelling again intensifies, and higher than normal values are reached throughout the region. The months of September, October, and November have near normal values at 30N and 24N latitudes and somewhat below normal values at 27N latitude. Below normal upwelling intensity is indicated during December except in the extreme south.

Values for 1972 and 1973

The upwelling index series presented by Bakun (1973) cover the years 1946 through 1971. In order to extend these series up to the

1974 data presented in Tables 12.1 and 12.2, values and anomalies of monthly upwelling indices for 1972 and 1973 are given in Appendix Tables 12.1 through 12.4.

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APPENDIX TABLE 12.1 - Monthly coastal upwelling indices for 1972. Units are cubic meters per second per 100 m length of coast. Negative values indicate onshore transport of surface waters and resultant downwelling.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	-98	-252	-93	-12	0	10	3	3	0	-5	-48	-100
60N 146W	-123	-302	-82	-12	1	14	4	1	-1	-9	-60	-116
57N 137W	-98	-258	-75	-26	-5	0	1	-18	-1	-28	-99	-131
54N 134W	-16	-83	-34	-17	-2	-3	3	-12	12	-11	-78	-27
51N 131W	2	-59	-25	3	2	6	17	4	38	9	-91	-7
48N 125W	-8	-83	-32	-5	11	27	15	26	8	5	-84	-66
45N 125W	-19	-103	-25	-1	34	55	52	56	19	34	-64	-68
42N 125W	-4	-64	-3	29	101	155	119	95	44	60	-34	-43
39N 125W	3	-19	22	90	184	254	191	162	81	41	-2	-2
36N 122W	10	5	107	147	183	228	197	179	83	4	1	4
33N 119W	8	33	168	228	243	283	254	201	144	36	16	24
30N 119W	91	88	186	180	165	168	125	113	90	61	67	85
27N 116W	120	138	199	236	196	162	101	58	94	64	77	81
24N 113W	85	77	161	196	179	156	53	12	84	24	59	45
21N 107W	86	86	128	117	74	97	4	-1	13	1	38	26

APPENDIX TABLE 12.2 - Monthly coastal upwelling index anomalies for 1972 relative to the 20-yr (1948-67) mean value for each month and location. Units are cubic meters per second per 100 m length of coast.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	40	-167	-47	-1	0	3	-3	-3	3	20	25	8
60N 146W	57	-199	-34	0	3	8	-1	-2	8	25	33	13
57N 137W	114	-140	-24	-3	6	0	0	-13	28	59	41	31
54N 134W	81	-15	-7	3	8	-4	1	-11	35	71	20	64
51N 131W	65	-24	-13	9	-2	-9	1	-8	41	50	-33	51
48N 125W	82	-36	-11	-5	-7	1	-19	5	4	43	3	34
45N 125W	75	-56	-10	-10	0	7	-22	6	3	54	10	26
42N 125W	63	-36	-6	-4	22	52	-13	4	8	60	8	15
39N 125W	16	-28	-14	22	60	86	9	23	18	21	5	10
36N 122W	0	-30	27	27	-20	-11	-2	-4	-10	-45	-11	-3
33N 119W	-11	-16	48	50	-39	-29	23	-12	7	-40	-5	14
30N 119W	35	10	70	39	-34	-31	-18	-29	-39	-42	2	31
27N 116W	49	45	80	88	-5	-33	-13	-46	-16	-42	3	18
24N 113W	35	2	68	80	36	28	5	-32	35	-45	7	6
21N 107W	68	46	31	17	-13	59	1	-6	27	16	30	17

APPENDIX TABLE 12.3 - Monthly coastal upwelling indices for 1973. Units are cubic meters per second per 100 m length of coast. Negative values indicate onshore transport of surface waters and resultant downwelling.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	-132	-84	-5	-6	-13	4	9	8	-4	-20	-71	-104
60N 146W	-133	-113	-11	-8	-16	7	14	11	-6	-28	-113	-168
57N 137W	-104	-122	-26	-32	-48	-4	0	2	-21	-86	-97	-213
54N 134W	-58	-62	-17	-23	-54	-23	-1	9	-15	-74	-5	-141
51N 131W	-75	-50	-3	5	-20	-15	5	40	-6	-19	2	-81
48N 125W	-151	-56	-7	23	9	11	32	54	0	-11	-26	-104
45N 125W	-111	-43	-1	43	25	27	76	103	3	-3	-46	-129
42N 125W	-89	-53	32	125	106	125	186	198	19	6	-41	-116
39N 125W	-49	-53	101	253	252	325	324	319	86	53	-7	-35
36N 122W	-2	-28	123	208	260	267	295	250	111	43	17	0
33N 119W	15	1	182	216	290	282	288	234	167	65	75	24
30N 119W	64	7	178	192	155	178	137	149	121	90	93	97
27N 116W	105	28	172	181	148	138	90	115	138	106	116	97
24N 113W	68	34	155	142	142	107	55	83	122	84	105	72
21N 107W	39	52	163	116	108	83	16	10	27	8	19	33

APPENDIX TABLE 12.4 - Monthly coastal upwelling index anomalies for 1973 relative to the 20-yr (1948-67) mean value for each month and location. Units are cubic meters per second per 100 m length of coast.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	6	1	5	41	-13	-3	3	2	-1	5	2	5
60N 146W	47	-10	4	37	-14	1	9	8	3	6	-19	-39
57N 137W	108	-5	-8	25	-37	-4	-1	8	8	2	43	-51
54N 134W	39	6	-3	10	-44	-23	-3	10	9	8	93	-50
51N 131W	-11	-14	10	9	-23	-30	-11	28	-3	21	60	-24
48N 125W	-61	-9	24	14	-8	-15	-2	32	-4	27	62	-3
45N 125W	-17	4	34	14	-9	-21	2	53	-13	16	28	-35
42N 125W	-23	-25	92	29	27	22	54	107	-16	6	1	-58
39N 125W	-36	-62	184	65	128	157	142	180	23	32	0	-22
36N 122W	-13	-63	88	43	57	29	97	67	18	-6	5	-7
33N 119W	-4	-48	38	61	8	-30	56	22	30	-12	53	14
30N 119W	8	-70	52	62	-44	-21	-6	7	-7	-13	28	44
27N 116W	34	-66	33	53	-53	-57	-24	10	28	0	42	33
24N 113W	17	-40	26	62	-1	-22	7	38	73	15	52	32
21N 107W	21	13	16	66	21	44	13	4	42	23	11	25

REVIEW OF THE PHYSICAL OCEANOGRAPHY OF GEORGES BANK*

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Abstract

Previously published information on the bathymetry, rotating tidal currents, temperature-salinity distribution and general circulation of the Gulf of Maine and Georges Bank are discussed. New information on surface temperature fronts in relation to monthly Ekman transport vectors is presented. Data on the distribution of herring larvae during successive periods during the autumns of 1972, 1973, and 1974 are used as evidence of dispersion and advection. Feasible approaches toward development of a circulation model are mentioned.

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Introduction

Thirty-seven and a half years ago as a young biologist I cut my oceanographic eyeteeth as we commenced a study of the distribution of certain planktonic species on Georges Bank. It became obvious over the next several years of the study that the key to the problem lay in an understanding of the circulation of the area. World War II interrupted the study, and in spite of intermittent attempts by numerous people and agencies over the intervening years, we still have only an approximate understanding of the circulation over Georges Bank, and many other continental shelf areas for that matter. We shall have to acquire a much better understanding of the dynamics if we are to evaluate the role of circulation in controlling dispersal of planktonic forms and organic production in general.

Hope springs eternal, even in the breast of one soon to retire from this field of endeavor. New techniques for making Eulerian and Lagrangian measurements are now at hand, and bright young minds are available to develop theoretical models to be compared with the real world measurements. It would appear that the chances for successfully defining the circulation scheme are now good if we are willing to make a serious attempt to elucidate it.

As background for developing a plan of attack on the problem, I shall briefly review the major known features of the physical oceanography of Georges Bank and the Gulf of Maine and then attempt to relate these features to what is known about the movement and dispersion of herring larvae. Finally I shall comment on what seem to be feasible approaches toward development of a circulation model.

Bathymetry

Uchupi's (1965) chart (Figure 1) handsomely illustrates the bathymetry of the Gulf of Maine, characterized by its rocky laybrinthine coastline and bottom topography on the north, its smoother coastline and bottom topography on the west, its deep basins interrupted by ridges and swells enclosed by the offshore banks, Browns and Georges which are intersected by the deep Northeast Channel and the shallow Great South Channel. The south side of Georges Bank is deeply penetrated by canyons, as the continental margin slopes away to the deep ocean basin.

Rotary Tidal Currents

One of the distinctive features of Georges Bank is the strong semi-diurnal rotary tidal currents with speeds ranging from a fraction of a knot to greater than 2 knots. Progressive vector diagrams for surface current measurements (the upper 14 feet) as reported in Haight (1942) and Anonymous (1973) are shown to scale in Figure 2. Those over

Georges Bank appear for the most part as elipses, with the long axes oriented NNW-SSE ranging from 4 to 8 miles in length. The short axes are 2 to 4.5 miles. Rotation is clockwise. Those over the northern edge of the bank and over the deeper parts of the south side are somewhat irregular. Those to the west of Georges, i.e., in Great South Channel and over Nantucket Shoals, have various orientations, the westernmost over the Nantucket Shoal and another east of Chatham having a NNE-SSW orientation. One directly east of Nantucket has a counterclockwise rotation. The number alongside each tidal elipse represents the sum of the hourly speeds over a 12 hour period, an approximation of the distance traveled by a parcel of water during that time. These range from 10.7 to 19.9 miles over the shallower parts of Georges Bank, as little as 6.5 miles near the southern edge and 5.5 miles off the northern edge and 8.8 to 19.4 miles off Nantucket. One thus might think of the tidal oscillation over Georges Bank as being like a semi-solid irrotational eliptical motion with a circumference of the order of 20 nautical miles over the shallow parts of the bank, grading off to 5-6 nautical miles over the deeper parts.

Temperature and Salinity Distribution

The profiles of Colton, et al. (1968) along the 67°30' meridian from the northern shore of the Gulf of Maine, across

Georges Bank to the slope water on the south provide a reasonably good characterization of the temperature/salinity depth distribution. Profiles for mid-December 1964 and 1965 are shown in Figure 3. Note that the deepest parts of the Gulf of Maine are slightly warmer and saltier than the waters above, the total range in temperature of the Gulf being 1 to 2° C, the total range in salinity from 2 to 2.5 ‰. The water over the bank is mixed vertically. An oceanographic front occurs well off the bank in December 1964, but lies above the 100 meter contour in December 1965.

In Figure 4 we see profiles for March 1965 and 1966. The temperature increases with depth everywhere throughout the Gulf of Maine. Over the bank the water is isothermal with a front along the southern edge, somewhat diffuse in 1965, very sharp in 1966. The salinity distribution on these occasions is markedly similar with increasing salinity with depth in the Gulf, isohaline conditions over the Bank and a salinity gradient between the southern edge of the Bank and the slope water.

Figure 5 represents the distributions in May 1965 and 1966. By this time a seasonal thermocline has begun to develop over the Gulf in the upper 50 meters below which the temperature increases with depth. Although warmer than in March the water is isothermal over the shallow (<50 m) parts of the bank with a slight thermocline beginning to develop over the deeper southern part producing an isolated cold core of "winter water" next to the bottom, which extends all the way westerly along the outer edge of the continental margin as far as about 38° N latitude, nicely illustrated in Whitcomb (1970). A bulge of this cold core extends out over the edge of the bank in the 1965 section. The temperature front between the Shelf and Slope water lies beyond this bulge in 1965, whereas it is close in over the edge of the shelf in 1966. The salinity distribution for May is almost identical with that for March.

In Figure 6 we can see the distribution for September 1965 and 1966. The strong thermocline which has developed over the central Gulf of Maine to a depth of 50 meters has begun to weaken. The coldest water appears at mid-depth with slightly warmer below. A temperature front appears at depth along the northern edge of Georges Bank occasioned by the colder vertically-mixed water over the bank. The cold core of winter water persists over the southern side of the bank and the sharp thermal front in the upper 50 meters lies just off the southern edge. The salinity distribution is little changed from that seen in May.

In discussing the general hydrographical conditions pertaining to Georges Bank, Clarke, Pierce, and Bumpus (1943) wrote in part:

"The depth of the major portion of Georges Bank lies between 40 m and 100 m, although areas of less than 25 m occur in the north central position, and shoals themselves are covered by only 5 to 15 m of water. Along the northern edge of the Bank the bottom drops rapidly from about 40 m to more than 200 m as the deep basin of the Gulf of Maine is approached. Along the southern edge the depth changes somewhat more gradually from 100 m to 200 m. Beyond 200 m it increases rapidly to about 2000 m.

"Georges Bank is therefore roughly speaking, a submerged, flat-topped plateau and it presents a sufficiently large obstacle to water movement to produce a profound effect on the ocean currents of this region.--

"The turbulence produced by the tidal currents and by the wind in the relatively shallow water overlying Georges Bank causes a vertical mixing of the water which results in a nearly uniform distribution of temperature and salinity from top to bottom at all seasons of the year, particularly in the central part of the bank. The bank water thus contrasts sharply with the surrounding water masses, which are typically stratified during all except the winter months. Since the temperatures and salinity values on the Bank are generally intermediate between those of the surface and deeper strata on the Gulf of Maine but usually much lower than those of the water lying to the south, we know that the bank water is originally derived, in a large part at least, from the Gulf. That portion of the Bank over which vertically uniform water was found is termed the Mixed Area, and all stations at which the salinity does not vary by more than 0.2 part per mille from surface to bottom are considered to lie within it. The limits of the Mixed Area are ordinarily rather sharp... ."

A review of the profiles presented in Colton, et al. (1968) reveals that the mixed area covers all of Georges Bank shallower than 50 meters in December, deepening to 80 meters in March and returning to an area of less than 50 meters in depth during the remainder of the year.

General Circulation of the Gulf of Maine

The development of our concepts of the circulation in the Gulf of Maine, including Georges Bank, have been documented in Bumpus (1973). It is not necessary to repeat that here but we shall review the circulation as described by Bumpus and Lauzier (1965) on the basis of drift bottle data, and Bumpus (1973) on the basis of drift bottle and sea-bed drifter data. There have also been a few experiments with drifting buoys which help to confirm or amplify the inferences made from the drift bottle data.

To quote from Bumpus and Lauzier (1965) relative to surface drift:

"Gulf of Maine -

"The indraft from off Cape Sable, from across Browns Bank and the eastern Gulf of Maine into the Bay of Fundy, is the chief characteristic during the winter season. A southerly flow develops along the western side of the Gulf of Maine and continues past Cape Cod through Great South Channel. Between the indraft in the Bay and the southerly flow along the western side of the Gulf several irregular eddies develop by February. An area of divergence north of Georges Bank is well developed by February.

"The Gulf of Maine eddy develops rapidly during the Spring months so that one large cyclonic gyre encompasses the whole of the Gulf of Maine by the end of May. There is an indraft on the eastern side of this gyre from the Scotian Shelf and Browns Bank. Abreast of Lurcher Shoals the drift may continue on northward into the Bay of Fundy or it may turn westward toward the coast of southern Maine, continue south and across Massachusetts Bay where it may divert into Cape Cod Bay or turn toward the east, north of Georges Bank.

"The Maine eddy, which reached its climax in May, begins to slow down in June. By autumn and winter the southern side breaks down into a drift across Georges Bank.

"Georges Bank -

"The few returned drift bottles from winter releases on Georges Bank suggest a southerly flow across this area during the winter months, with a westerly component across Great South Channel. During the Spring months an anti-cyclonic eddy develops over Georges Bank. The northern side of this Georges eddy is common with the southern side of the Maine eddy; an area of divergence continues along the northern edge of Georges Bank. A persistent westerly drift along the southern side of the Bank continues across Great South Channel.

"During the summer the eastern side of the Georges eddy veers southerly and off-shore. With the onset of atutumn the west side of the Georges eddy breaks down into a westerly and southerly drift."

Bumpus (1973) points out that the limited drift bottle data for the 1960-1970 period in the Gulf of Maine and over Georges Bank add very little to our previous understanding of the circulations in that area.

One may note, however, that the diagrams in Bumpus and Lauzier (1965) indicate the speeds of residual drift range from 1 to 8 nautical miles per day, the greater speeds restricted to the approaches of the Bay of Fundy or the western side of the Gulf of Maine, where the circulation is significantly influenced by river runoff. The drifts over Georges Bank are frequently on the order of 2 to 3 nautical miles per day, although greater speeds have occasionally been inferred. The classic diagram of Bigelow (1927), Figure 7, illustrates as well as any the general circulation pattern.

Thus to return to our "semi-solid irrotational eliptical motion" induced by the tide over Georges Bank, we might now add a clockwise rotation of 2-3 miles per day. We might liken this surface circulation over Georges Bank to a very slowly clockwise turning record in a record player estimated at one rotation per 100 days (3.6 rotations/year) on a spindle with a large (8 mile by 4 mile) eliptical eccentricity.

As for the bottom drift, Bumpus (1973) in reporting on the sea-bed drifter results states: "A persistent and continuous bottom drift of 0.5 ± 0.2 nautical mile/day extends toward the southern tip of Nova Scotia and the eastern side of the Bay of Fundy from Browns and LeHave Banks east of the Northeast Channel. This is in agreement with Lauzier's (1967) findings. Along the western side of the Gulf of Maine the drifts next to the coast tend to flow directly ashore, whereas farther offshore the drift is more nearly parallel with the coast in a westerly direction. Fewer than 10% of the drifters are recovered from the deeper parts of the Gulf of Maine and from Georges Bank whereas returns are substantially greater from the periphery of the Gulf of Maine and from the Continental Shelf west of Nantucket Shoals. The drifts in the deep parts (>100 m) are less than 0.1 nautical mile/day whereas those from Georges Bank are on the order of 1 nautical mile/day. A line of divergence occurs at Northeast Channel with northerly drifts north and east of the channel and westerly drifts south of it. In general, the drifts over Georges Bank follow a clockwise rotation around the shoals with a net drift to the west and across Great South Channel."

Because there are so few returns of drift bottles and sea-bed drifters from Georges Bank, one cannot help but suspect that a great number are carried offshore, rather than drifting to the west to strand, in the case of drift bottles, or be recovered by fishermen's trawls, in the case of sea-bed drifters.

Certainly when one views the results of some drogued drifting buoy experiments conducted jointly by the U. S. Fish and Wildlife Service and the Woods Hole Oceanographic Institution in 1957, one obtains the feeling that there are ample opportunities for exchanges between Georges Bank water and Slope water. Buoys equipped with on-demand radio signals were located via ship or air-borne radio direction finders. They drifted with the top five meters of the water column.

One experiment, Figure 8, was conducted between Northeast Peak and central Georges during the period 15 April to 10 June, 1957. Buoys set out at the Northeast Peak (Mike and India) moved rapidly, more than 5 miles per day, and southerly into deep water. Buoys launched in the shallower areas exhibited a slower net movement, between 1 and 4 miles per day, in a clockwise rotation. Buoy Hotel, after a slow southwesterly movement (81 miles in 55 days), suddenly increased speed and moved 128 miles to the WSW in 12 days. Buoy November, which failed to respond after the 21st of April, was reported on 20 June just east of Hudson Canyon on the 1000 fathom contour, possibly having run parallel to the track of Hotel. This buoy, November, was subsequently sighted 500 miles to the eastward (38° 42' N, 60° 30' W) on 31 July, obviously drawn into the Gulf Stream.

Another experiment with four drift buoys was conducted during 9-17 October 1957 in the South Channel area, Figure 9. An easterly drift along the northern edge of the bank, between 6 and 13 miles per day was indicated, with a slower, less definite drift in the center of the channel, and a southerly set of about 5 miles per day on the western side of the channel.

Five more buoys were set out on December 6, 7, and 17, 1957, Figure 10. Hotel, launched on the southeastern part of the bank subsequently failed to function and is not shown in the figure. It was recovered about 500 miles to the SE 8 months later. Mike was picked up and replaced by a fisherman, but was apparently damaged as it ceased to respond to radio calls. It had moved 50 miles eastward in 12 days. The remainder were repeatedly located during December. This experiment yields evidence of an easterly set on Georges Bank in December 1957 on the order of >1 to >4 miles per day as indicated by Papa and Mike. Papa eventually drifted off into deep water southeast of the bank where it was sighted. India moved at a similar rate but skirted the northern edge of Georges, then turned northerly before reaching Browns Bank, being ultimately recovered by a fisherman 21 miles SE of Matinicus Rock. This buoy was obviously in the Gulf eddy. Alpha following the innerpart of the Gulf eddy, moved more slowly, at >5 miles per day.

This experiment perhaps explains why so few drift bottles set out on Georges during the autumn and winter have been recovered. The Georges eddy has given way to an easterly drift. Bigelow (1927, p. 864-5) examined the current measurements made by the U. S. Coast and Geodetic Survey during 1911 and 1912 at Nantucket Lightship. This analysis showed "a dominant drift toward the north and west during the spring, summer, and early autumn, averaging about 3.4 miles per day; but about as strong a southeasterly set (3 miles daily) during the late autumn, winter, and early spring, averaging about S. 50° E (SE × E) in direction." Bigelow credited the presence of the strong northwest winds of the season with the reversal in drift. During our December experiment the winds were predominantely from the southwest, with strong easterlies on a few occasions. Whatever the reason, the surface drift across Georges Bank during the autumn and winter is different and apparently contrary to the drift of other seasons. It is quite probable, at this stage of our information, that the net circulation on Georges Bank is not readily predictable. It is reasonable to expect that the water movements on the Bank, especially during those seasons where the water is well mixed, respond to the short-term wind effects as postulated by Chase (1955) for Georges Bank in regard to Haddock larvae and as reported by Howe (1962) in the Middle Atlantic Bight and more recently Beardsley and Butman (1974). The latter authors with measurements south of New England demonstrated that short intense wind events dominate the circulation over the shelf in winter and account for most of the observed net flow. Their observations show that large westward mass transports along the shelf were produced by strong easterly winds and the sea level rise at the coast (see Miller, 1957), while westerly winds produced little along-shore flow. However, the storm producing the westerly winds was much weaker than the one with the easterly winds. It may be that we cannot extrapolate the southern New England Shelf response to Georges Bank because the geography is quite different. However, it is quite possible that when an intense low pressure cell moves south of Georges causing easterly winds over the Bank and an increase in sea level over the shoals, there will be a strong net westerly flow over the south side of the bank. Contrarywise, an intense low passing north of Georges could similarly create strong easterly flows along the north side of the bank, with weaker flows south of the shoals.

Sea Surface Temperature Fronts

As we have seen from Colton's profiles, the interface between the colder, less saline Shelf Water and warmer, more saline Slope Water appears at the sea surface as a thermal front. This front can be observed by satellite-borne infra-red radiometers. The National Environmental Satellite Service prepares charts of the sea surface temperature fronts off the east coast of the U. S. on a weekly basis. Ingham and co-workers at the NMFS Atlantic Environmental Group have used these charts to monitor and analyze the position of the Shelf Water front from June 1973 through December 1974. Figure 11 is an example. Figure 12 is a composite of the frontal positions during September-December 1973 and 1974. The dashed line represents the shelf edge as defined by the 100 fathom contour.

In the course of the analysis the temporal variation of the Shelf Water front was established along certain standard lines (Figure 11). The results of the first four, Casco Bay 120°, 140°, 160°, and Nantucket 180° are shown in Figure 13. The location of the front is plotted as the distance from the shelf edge to the front.

The mean position of the front during the 18 month period is shown in Table 1. The variability of the front's position, as indicated by the standard deviation, is large on all azimuths, being largest at the eastern corner of Georges Bank and least south of Nantucket.

Table 1

Bearing Line	Sample Size	Distance from shelf edge (Km) + = shoreward, - = seaward	Standard Deviation
Casco Bay 120	30	-45.5	70.9
140	31	-35.4	64.0
160	36	- 6.1	39.3
Nantucket 180	37	+ 0.6	38.5

Major offshore excursions occurred on the Casco 120° line in July and October 1973 and during the winter of 1974; on Casco 140° line in July 1973 and during the winter and early spring of 1974; on Casco 160° line during March of 1974 and on the Nantucket 180° line during June and November 1973 and winter of 1974. Intrusions of Slope Water appear greater on the Casco 160° and Nantucket 180° lines than over the eastern parts of Georges. On Casco 160° the intrusions occurred during June 1973 and during the summer of 1974 whereas they were fairly extensive on the Nantucket 180° line during the summers of 1973 and 1974. Ingham estimates 14% of Georges was invaded by Slope Water in late August 1974, increasing to 18% coverage by early September, then decreasing to about 4% by the end of the month. He states: "At no time during the year did the invasion of the Bank by Slope Water exceed 18% and the average coverage for the year was 3.5%, with a standard deviation of 4.8% based on a sample of 30 observations."

Wright (1975) has carefully examined the position of the Shelf Water/Slope Water boundary between 69° and 72° W longitude, an area which slightly overlaps our area of interest. His study shows that this interface, identified by the 10° isotherm, intersects the bottom within 16 Km of the 100 meter contour about 80% of the time, with a seasonal progression from south in the winter to north in the autumn. The sea surface boundary position is much more variable, averaging 45 Km seaward of the 100 meter contour in winter and 75 Km seaward in late summer. This boundary is much more nearly horizontal than vertical. He also finds detached parcels of shelf water in the slope water at all seasons of the year.

Estimates of Wind-Driven Ekman Transports

The Pacific Environmental Group of the N.M.F.S. provides estimates of monthly wind-driven Ekman transports computed from the monthly average atmospheric pressure charts after the method of Fofonoff (1962) as described by Bakun (1973). Figure 14 shows the estimated monthly Ekman Transport at 40° N 70° W for 1972, 1973, and 1974. It is quite obvious from this figure that the direction and intensity of the transport is extremely variable from month to month and from year to year. One is not at all assured either that the water movements are going to be in the direction of the computed Ekman transports, in the shallow waters of Georges Bank and Nantucket Shoals. They may indeed be more directly downwind, i.e., 90° to the left of these Ekman transport vectors. What these vectors mean to me is that there are periods of intense forcing which may indeed induce extreme wind-stressed flows as well as periods of minimal forcing.

We have compared the data for 40° N 70° W with data for 39° N 69° W, 39° N 66° W, 42° N 60° W, and 42° N 66° W for 1974 and found the 40° N 70° W representative of the area. However, the position of the fronts relative to the edge of the bank in the last half of 1973 and all of 1974 do not appear to correlate well with the monthly Ekman transport vectors. It is very possible that the development of eddies north of the Gulf Stream have a significant impact on the location of the Shelf Water-Slope Water front.

Evidence from the Distribution of Herring Larvae

We have inspected the information presented by Schnack and Stobo (1973) and Schnack (1974) summarizing the results of the 1972 and 1973 joint herring larval surveys and the several separate reports on the 1974 cruises. These cruises took place as follows:

1972	1973	1974
22-30 Sep	16-28 Sep	6-24 Sep
2-28 Oct	29 Sep-20 Oct	27 Sep-18 Oct
12-28 Oct	15 Oct-1 Nov	18-30 Oct
31 Oct-12 Nov	28 Oct-8 Nov	16-23 Nov
28 Nov-15 Dec	4-20 Dec	4-19 Dec

We have delineated the areas where 10 or more herring larvae per 10 m^2 were caught, Figures 15, 16, and 17, and made some inferences from the distributions of the various size categories. We have inferred that the area occupied by herring larvae <10 mm in length to be the spawning area and have outlined it and the spawning area for the preceding cruise. We have then outlined the area occupied by the 10-15 mm larvae and the >15 mm larvae and drawn arrows representing the inferred spread of the larval distribution of the larger size categories from the spawning areas. It is quite apparent that advection and dispersion have occurred.

The spread from the "spawning area" between the first and second cruises in 1972 appears to be on the order of one mile per day and due to dispersion by the tidal oscillation. Between the second and third cruises an advective spread of >10 miles per day southwestward occurred with a lesser northerly drift north of Georges Shoal and northeasterly drift from Nantucket Shoals. Between the third and fourth cruises mixed movements of 1-2 miles per day occurred over Georges Bank, but a four mile per day spread occurred westward from Nantucket Shoals spawing area. By the fifth cruise herring larvae are well spread over the whole area, the major drift having been westward from Nantucket Shoals at about two miles per day. It would appear that there had been no drifts away from the shallow waters except for a small tongue of 10-15 mm larvae over the edge of SE Georges on the second cruise. An anticyclonic eddy was drifting westward just south of Georges Bank during this period (U.S. Naval Oceanographic Office, 1972).

During the interval between the first and second cruises of 1973 there was a southwestward advection from the Georges spawning area of about five miles per day and a weak southeasterly drift. Between the second and third cruise the southwestward drift continued coupled with a general expansion from the Nantucket Shoals spawning area and possibly a northeastward drift along the NW side of Georges. The westward drift continued between the third and fourth cruises and a weak southerly drift was apparent between the fourth and fifth cruises. The larval population was larger in 1973 than in 1972 and tended to move closer to the southern edge of Georges Bank or even beyond the 100 meter contour during 1973. There were no anticyclonic Gulf Stream eddies in the vicinity during this period (U.S. Naval Oceanographic Office, 1973).

Spawning was late in 1974 so that no herring larvae were caught during the first cruise. Between the second and third cruises there appear to be westward advections from the spawning areas at speeds of 3 to 8 miles per day. Between the third and fourth cruises there appeared a general dispersion from the spawning areas. Between the fourth and fifth cruises the overall tendency was for the area occupied by larval herring to compress slightly latitudinally with a slight westward drift of the whole at between 1 and 2 miles per day. As in 1973, the larval herring population tended to extend beyond the limits of the

100 meter contour. The computed monthly Ekman transports during this period were moderate toward the SW, being somewhat stronger in October than for the 10-year mean for October, which is usually weak. It is interesting to note that an anticyclonic eddy drifted during November from the vicinity of the Gulf Stream to the southern edge of Georges Bank and continued westward along the edge during December (U.S. Naval Oceanographic Office, 1974).

Table 2 provides us with an idea of how the total population of herring larvae changes from cruise to cruise in relation to the change in area occupied. It is apparent from this information that the herring population tends to increase at a greater rate than the area it occupies through the end of October (the third cruise) but somewhat later in 1974, and then begins to decrease due to the various exigencies which cause a decrease in the population while the area occupied by the population continues to increase through the fourth cruise (prior to the first of December) following which the area decreases slightly.

The evidence from the Joint Herring Larvae Surveys appears to suggest that the larvae are retained within the shelf water. The area they occupy expands with time due to the vigorous tidal stirring and advection. The advection appears to be principally toward the west. There are some indications of a northeasterly drift north of Georges Shoal, i.e., a continuation of a clockwise gyre around the shoal

Table 2

Change in total number of herring larvae and area occupied from cruise to cruise

	Δ Total Number of Herring Larvae			Δ Area		
	1972	1973	1974	1972	1973	1974
From 1st to 2nd cruise	3.8*	24	-	4.7	5.0	-
From 2nd to 3rd cruise	1.5	2.5	1.3	1.2	1.6	1.3
From 3rd to 4th cruise	.42	.64	1.4	1.1	1.3	3.0
From 4th to 5th cruise	.34	.16	.47	.73	.80	.82

*Georges Bank only.

part of the bank. We do not have adequate data to evaluate the effect of the passage of storms through the area.

It is possible that some larvae may drift off the southeast edge of Georges Bank. This is the location where the thermal fronts, as observed by satellite, appear to have their maximum excursion. It is also possible that the anticyclonic eddies drifting away from the Gulf Stream along the southern edge of the bank may entrain shelf water along their perimeter. The sampling pattern for larval herring may not extend far enough off the bank in this vicinity. It is also fairly obvious that we do not know how far the larvae drift west of Nantucket Shoals in November and December, inasmuch as the sampling is not adequate west of 71° W longitude.

Summary

In summary, we are dealing with an area which has the temperature and salinity characteristics of the Continental Shelf bordering on Slope Water to the south. The front between the Shelf and Slope water ranges from diffuse to very sharp and it frequently wanders large distances (several hundreds of kilometers) at the surface, probably much shorter distances (tens of kilometers) at the bottom. Anticyclonic eddies from the Gulf Stream drift close to the southern edge of the bank, impinging directly against it as they move westward. The energetic tidal oscillations over the bank are predictable whereas the net drifts are much less understood. There appears to be a clockwise rotation around the bank during the seasons when the thermocline is developing. At other seasons it would appear that the winds may be the mechanism for providing advective forces of the sea surface.

It is high time that a concerted effort be made to understand the advective processes above and around Georges Bank and the physical forces which regulate them!

In order to determine how the circulation is conditioned by the wind systems, it would seem that a drogued buoy program should be conducted with initial buoy plantings in the spawning areas. The movements of these buoys should be related to the daily, or better still, 6 hourly, components of the wind stress. Equipping the drogues with recording thermistors or conductivity meters would provide some clues as to how well the buoys stay within the shelf water. The presence of the winter water, as seen in Figure 6, is engimatic. Does this water move at all? Is there a shear zone above it? Drogues should be placed in it and above it to determine this.

The forcing by the wind and an evaluation of the Ekman transport needs also to be determined by judicious employment of current meter arrays at the northern and southern edges of the bank, with at least one array over a shallower part of the bank. Equipping these current meter arrays with conductivity cells would permit an estimate of the flux of salt across the bank and its boundaries.

Both Lagrangian and Eulerian current measurement studies should be accompanied by concurrent synoptic temperature and salinity profiles in order to gain a clear understanding of the characteristics of the water being advected. Sampling for nutrients along these profiles would also make it possible to estimate nutrient fluxes across isobaths so necessary in the evaluation of primary production.

As learning proceeds the locations of fixed and drifting elements of the experiments should be modified to develop time and space scales of the transport processes. Assistance from oceanographers skilled in the technical and theoretical aspects of this research should be enlisted.

Acknowledgements

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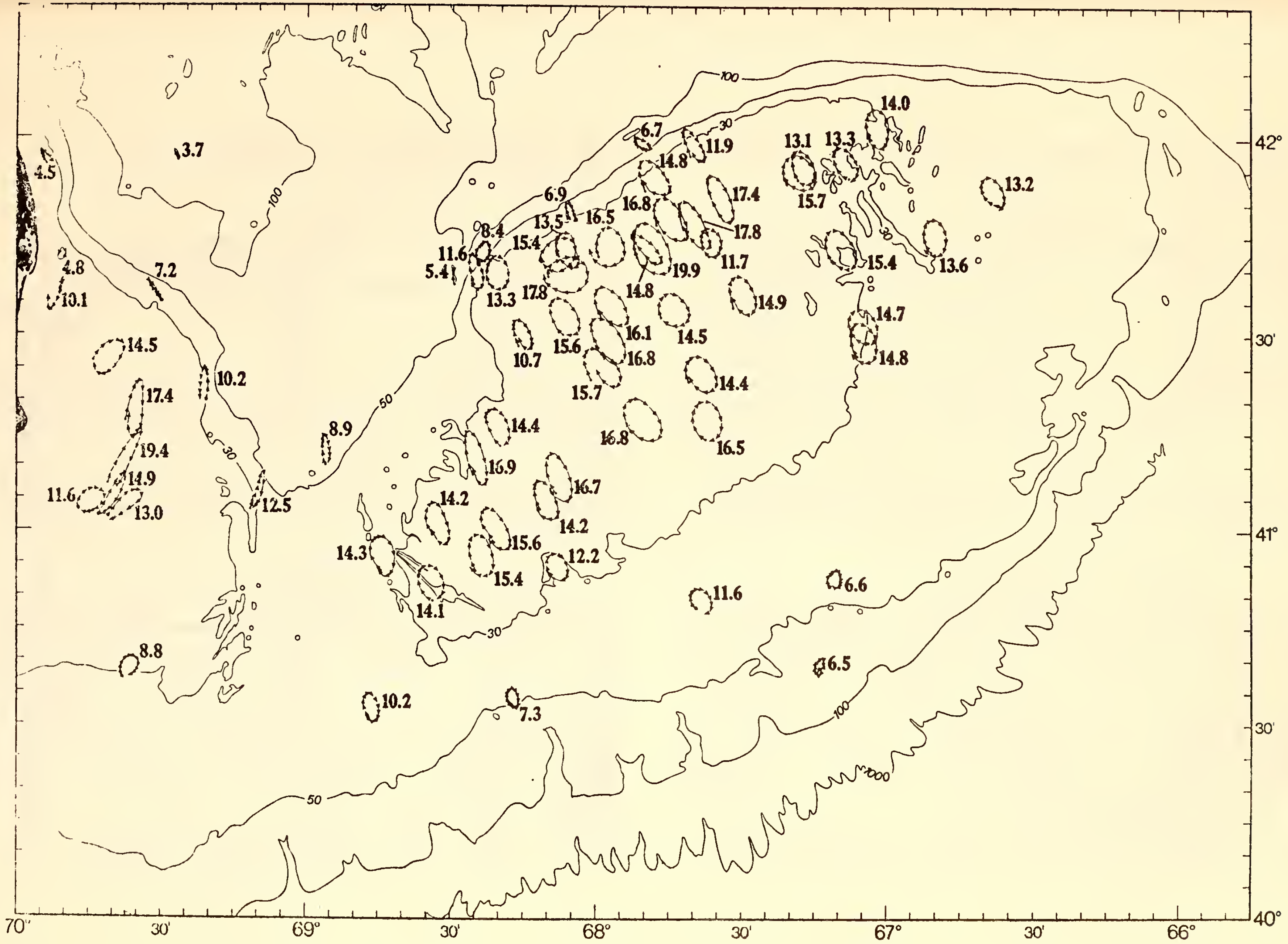
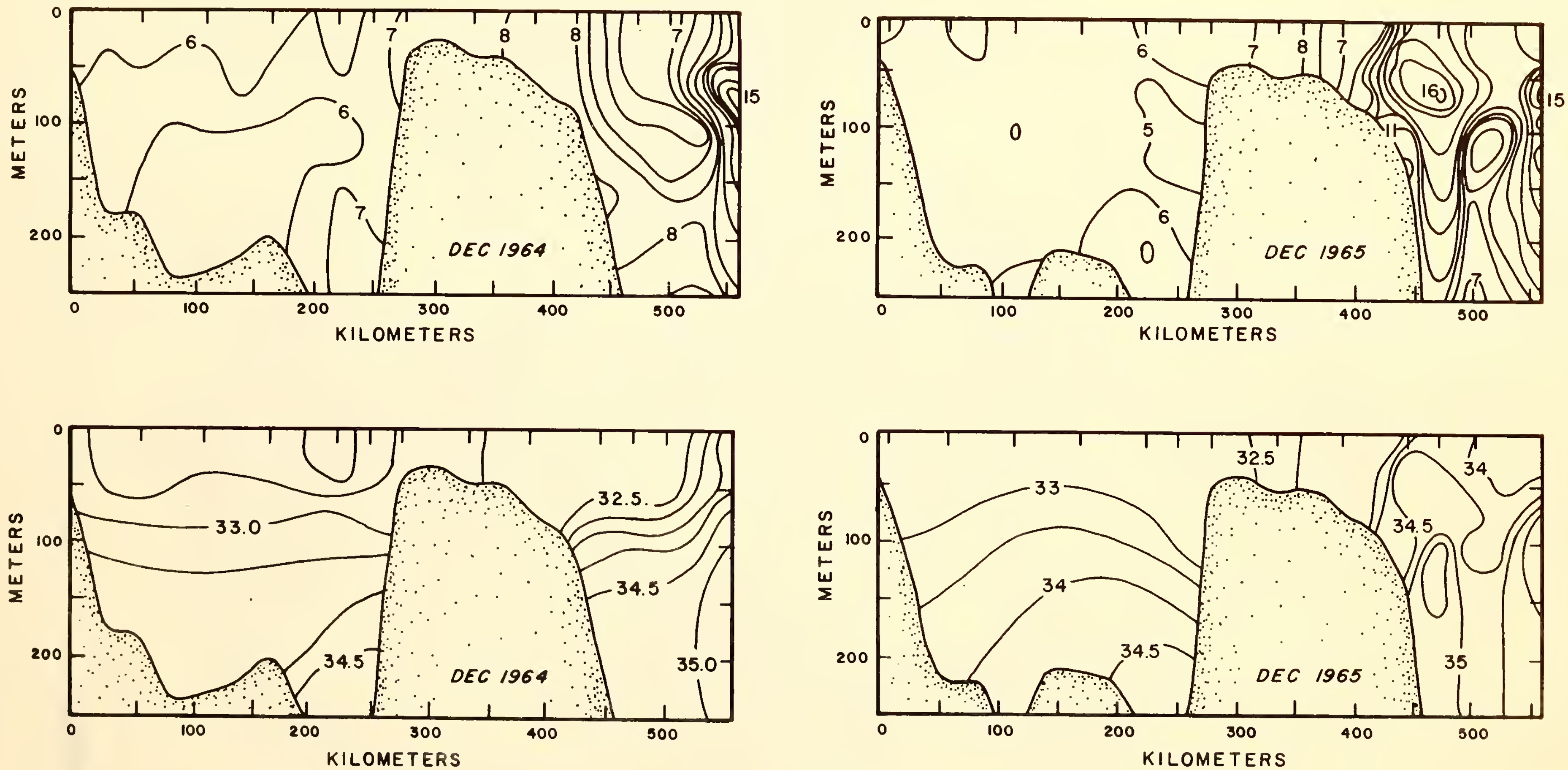
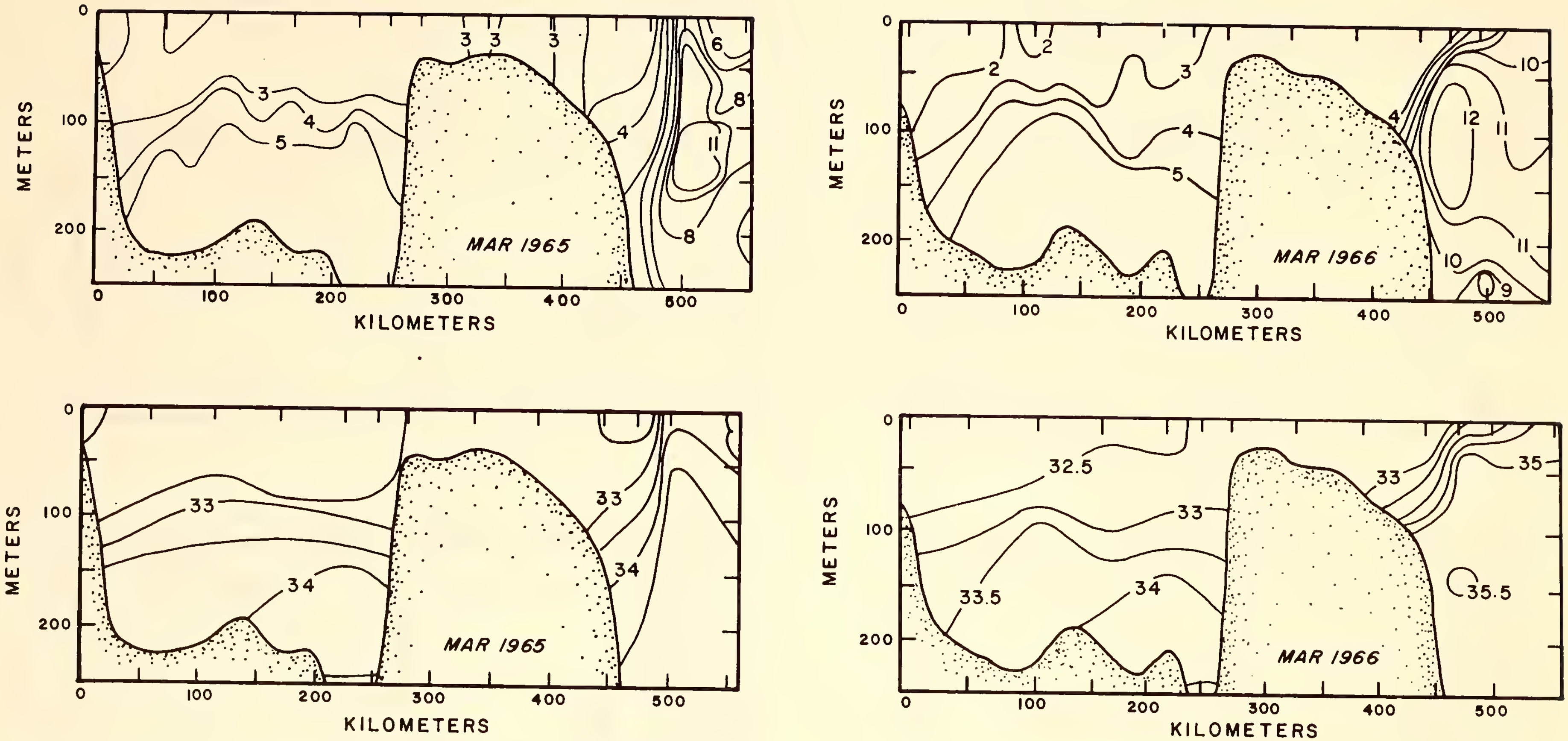
13.1 Bathymetry of the Gulf of Maine (Uchupi, 1965).



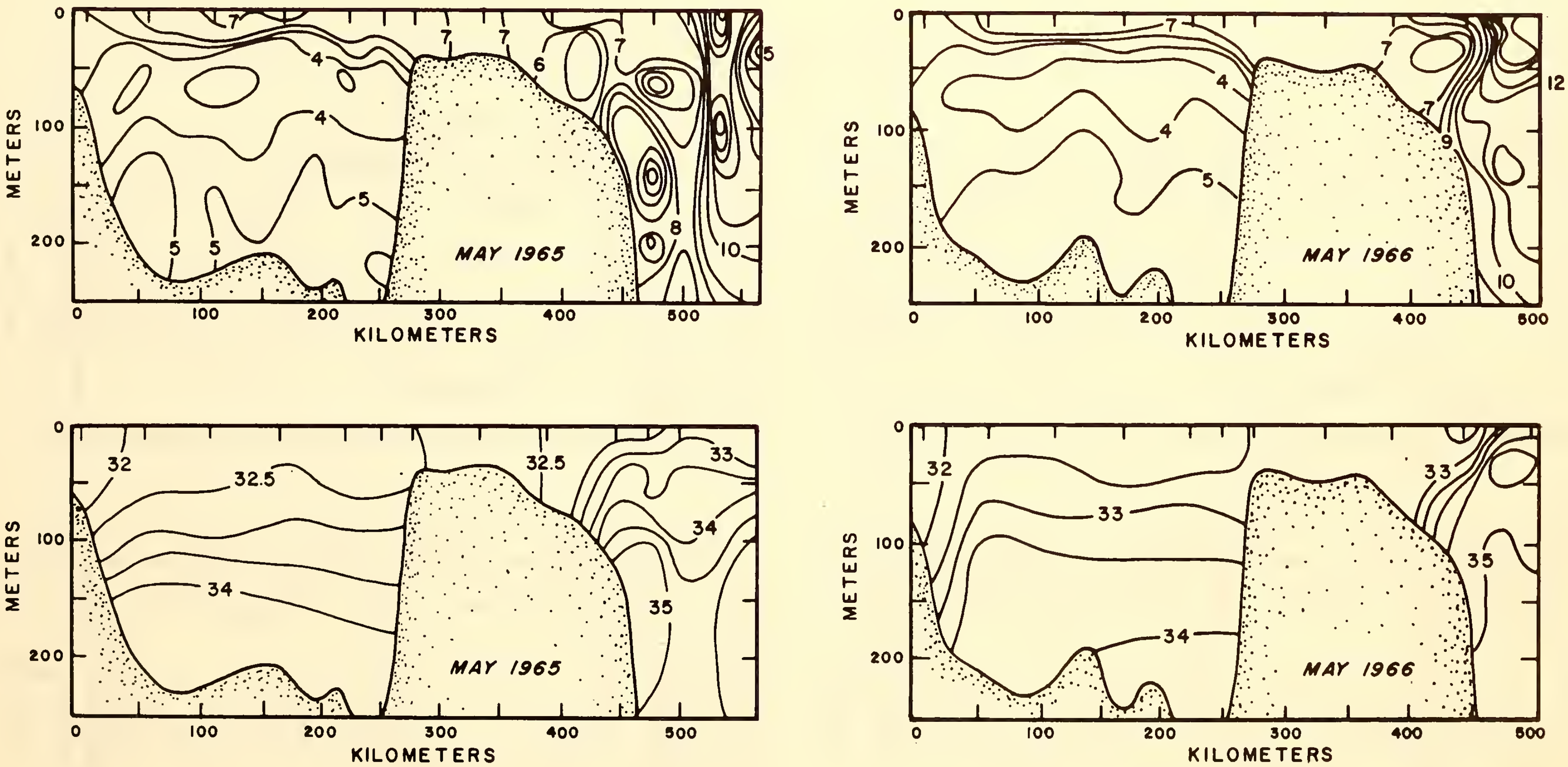
13.2 Progressive vector diagrams of tidal oscillations on Georges Bank drawn to chart scale.



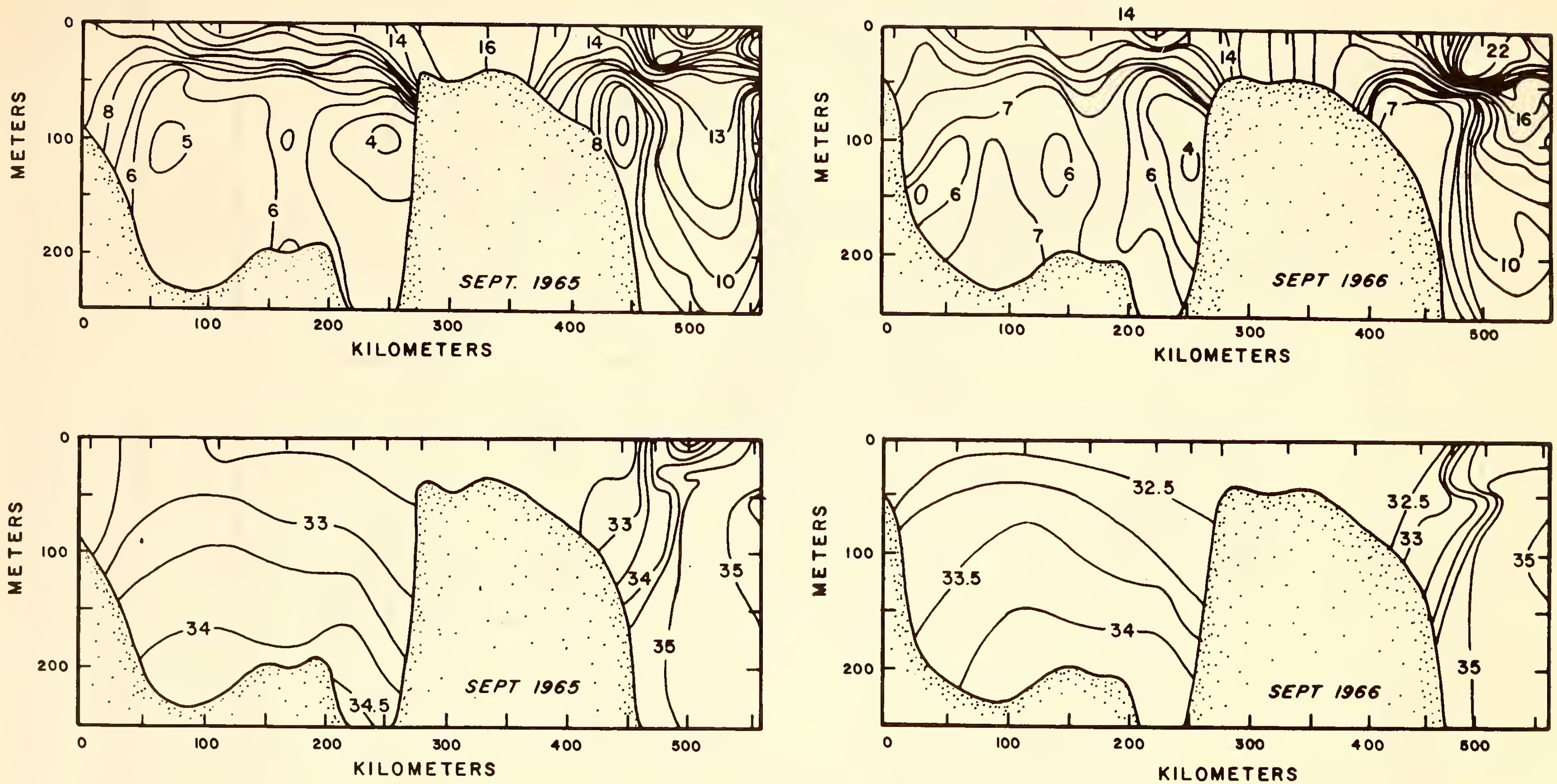
13.3 Temperature, salinity profiles along 67°30'W across Gulf of Maine for December 1964 and 1965 (Colton, et al. 1968).



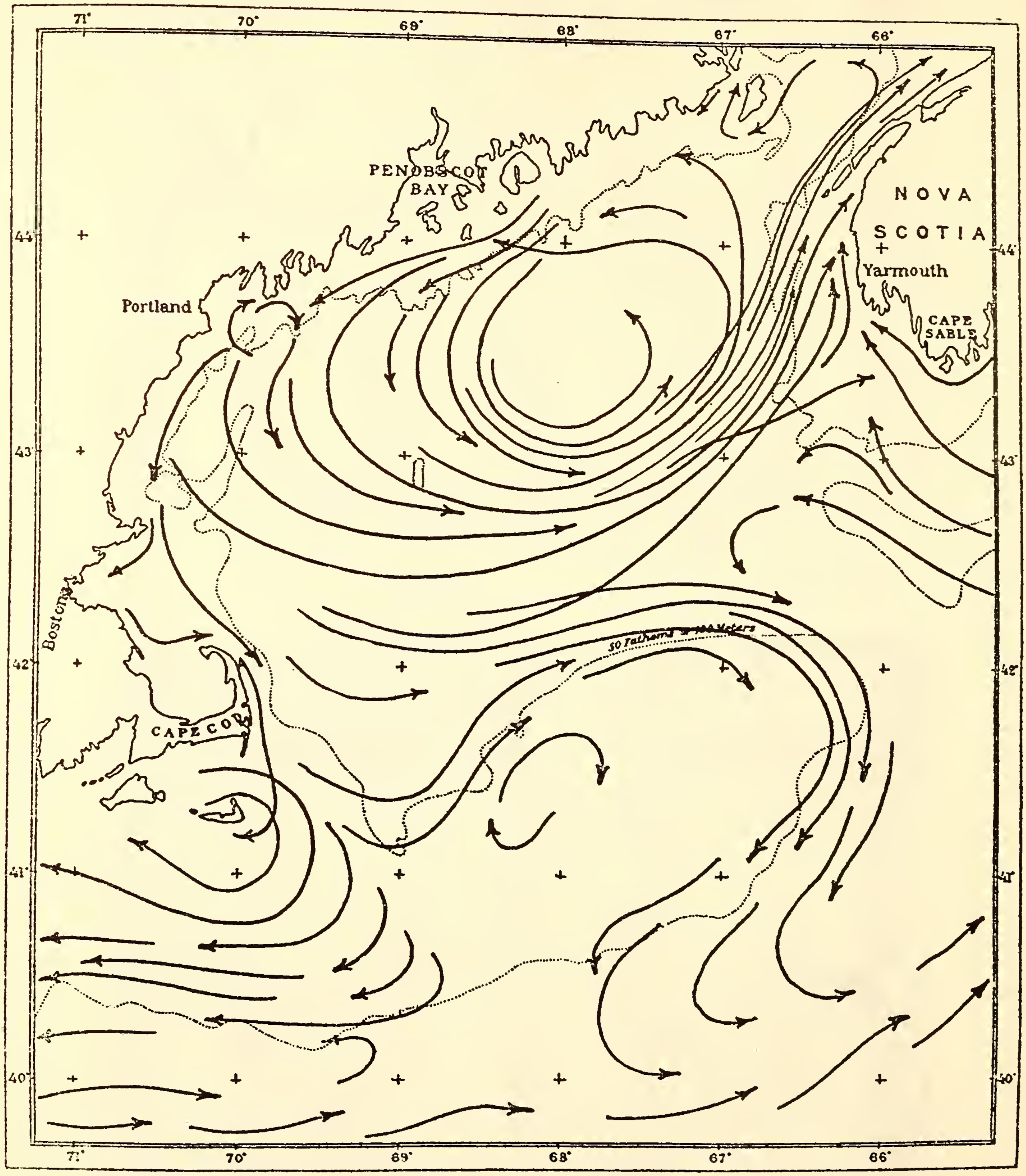
13.4 Temperature, salinity profiles along 67°30'W across Gulf of Maine for March 1965 and 1966 (Colton, et al. 1968).



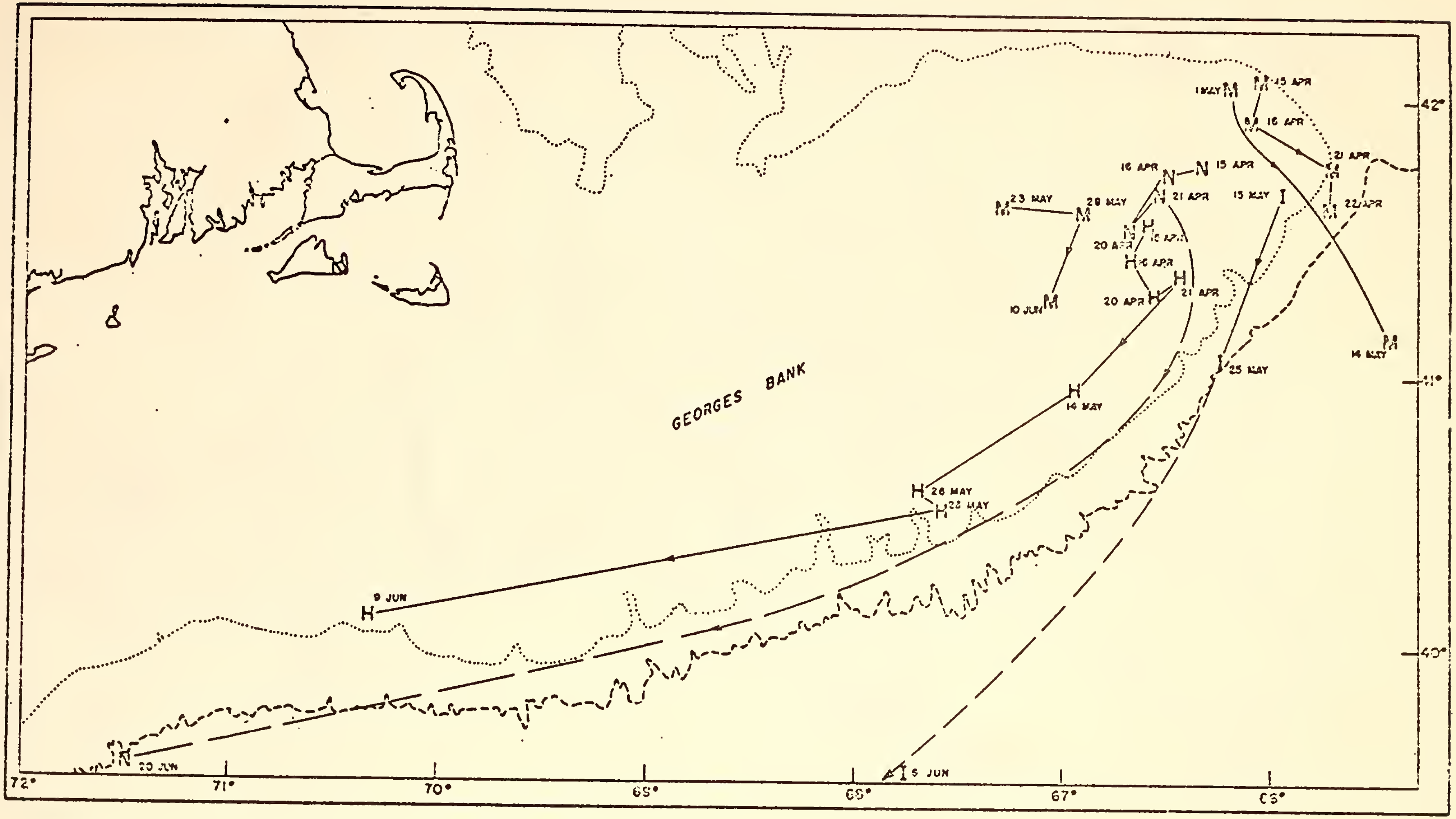
13.5 Temperature, salinity profiles along 67°30'W across Gulf of Maine for May 1965 and 1966 (Colton, et al. 1968).



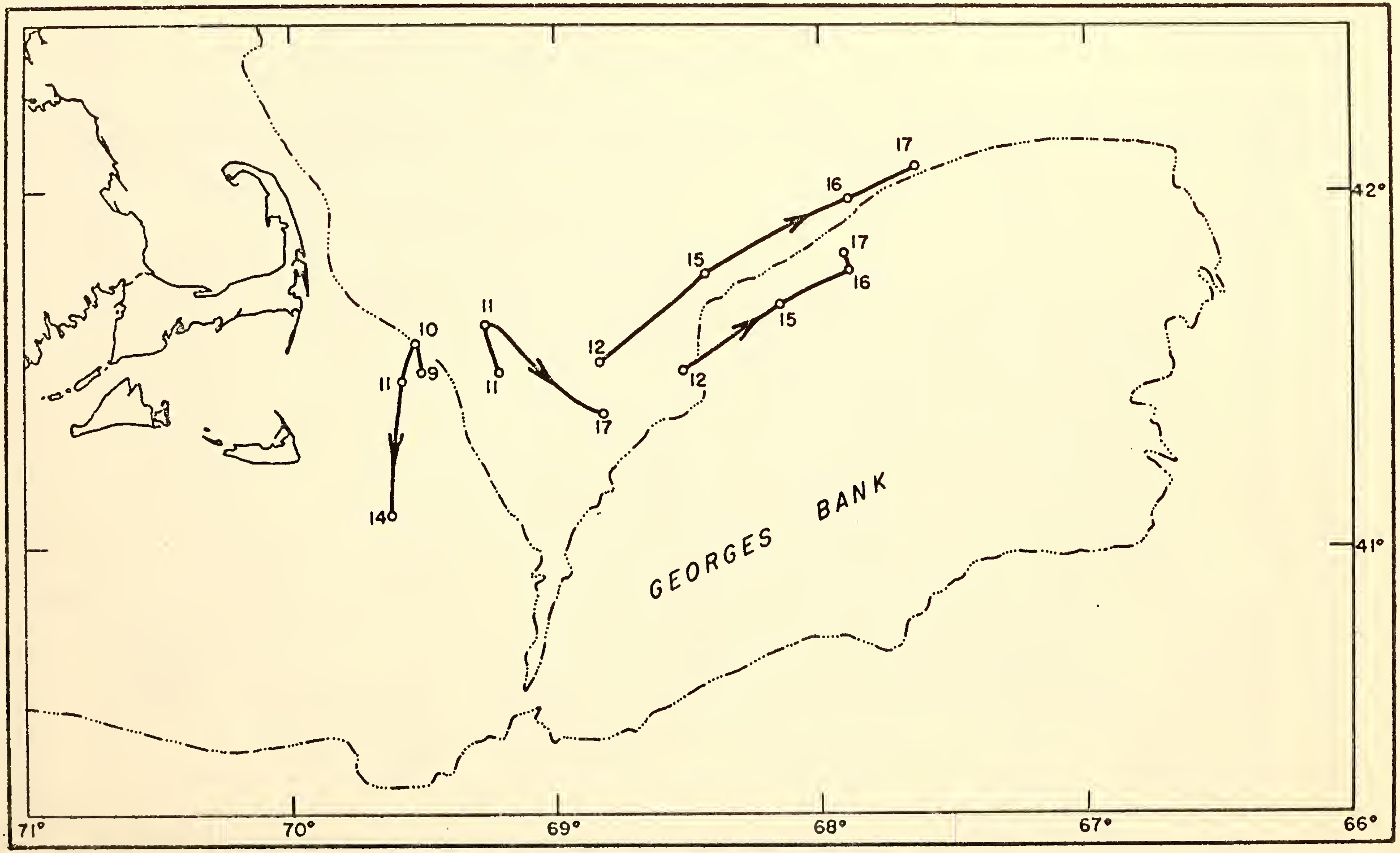
13.6 Temperature, salinity profiles along 67°30'W across Gulf of Maine for September 1965 and 1966 (Colton, et al. 1968).



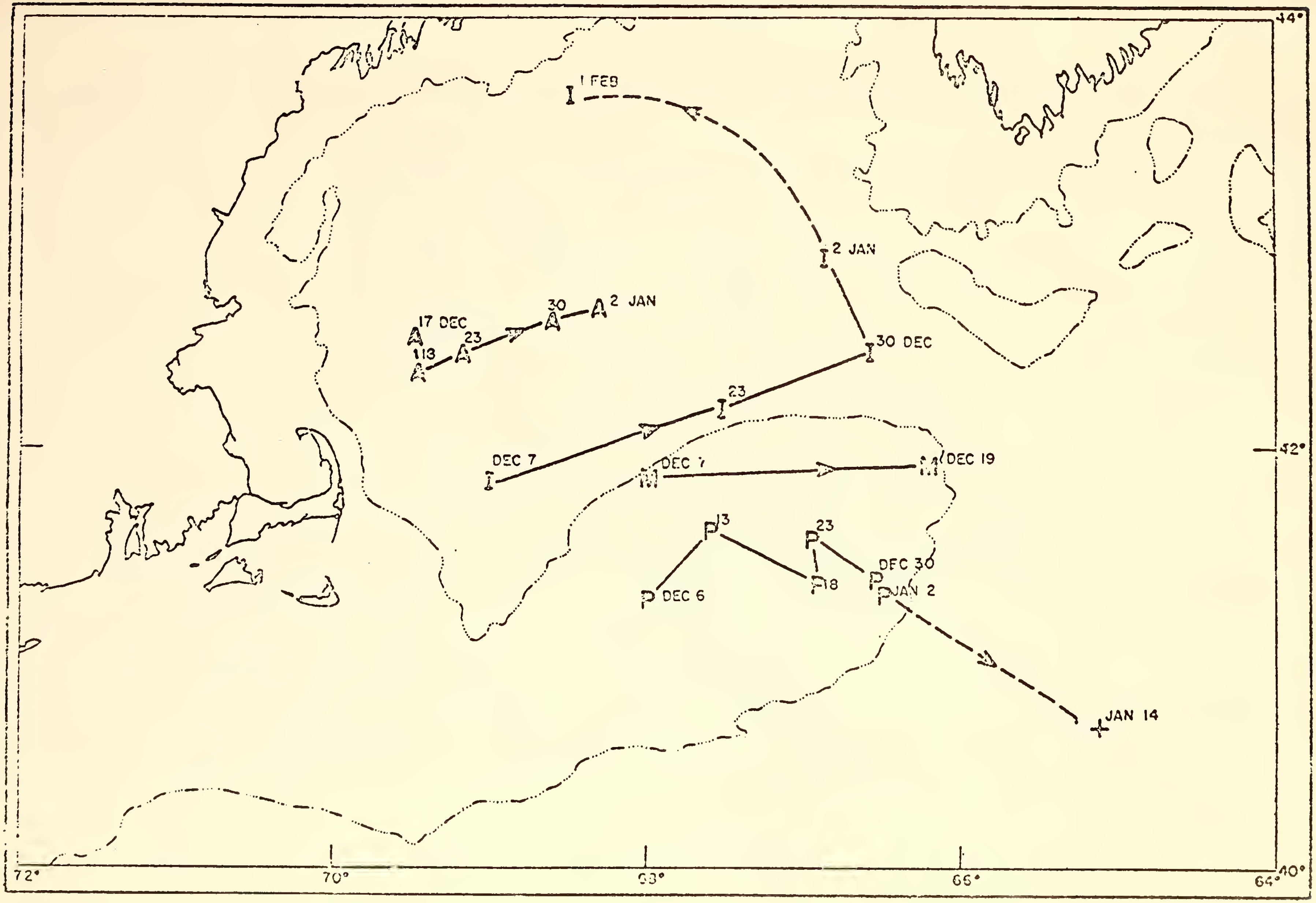
13.7 Schematic representation of the dominant non-tidal circulation of the Gulf of Maine July to August (Bigelow, 1927).



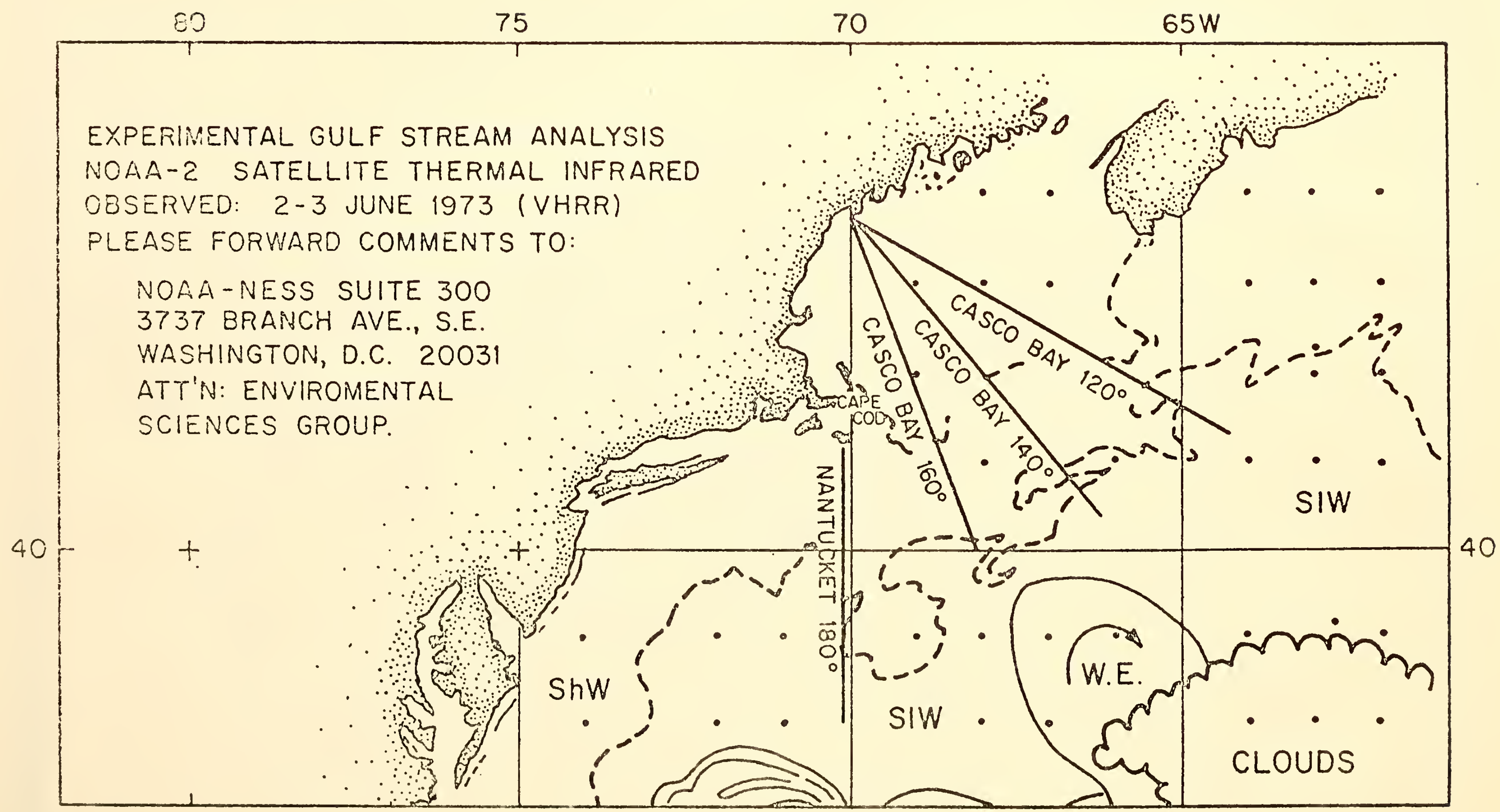
13.8 Drift buoy trajectories 15 April to 10 June, 1957.



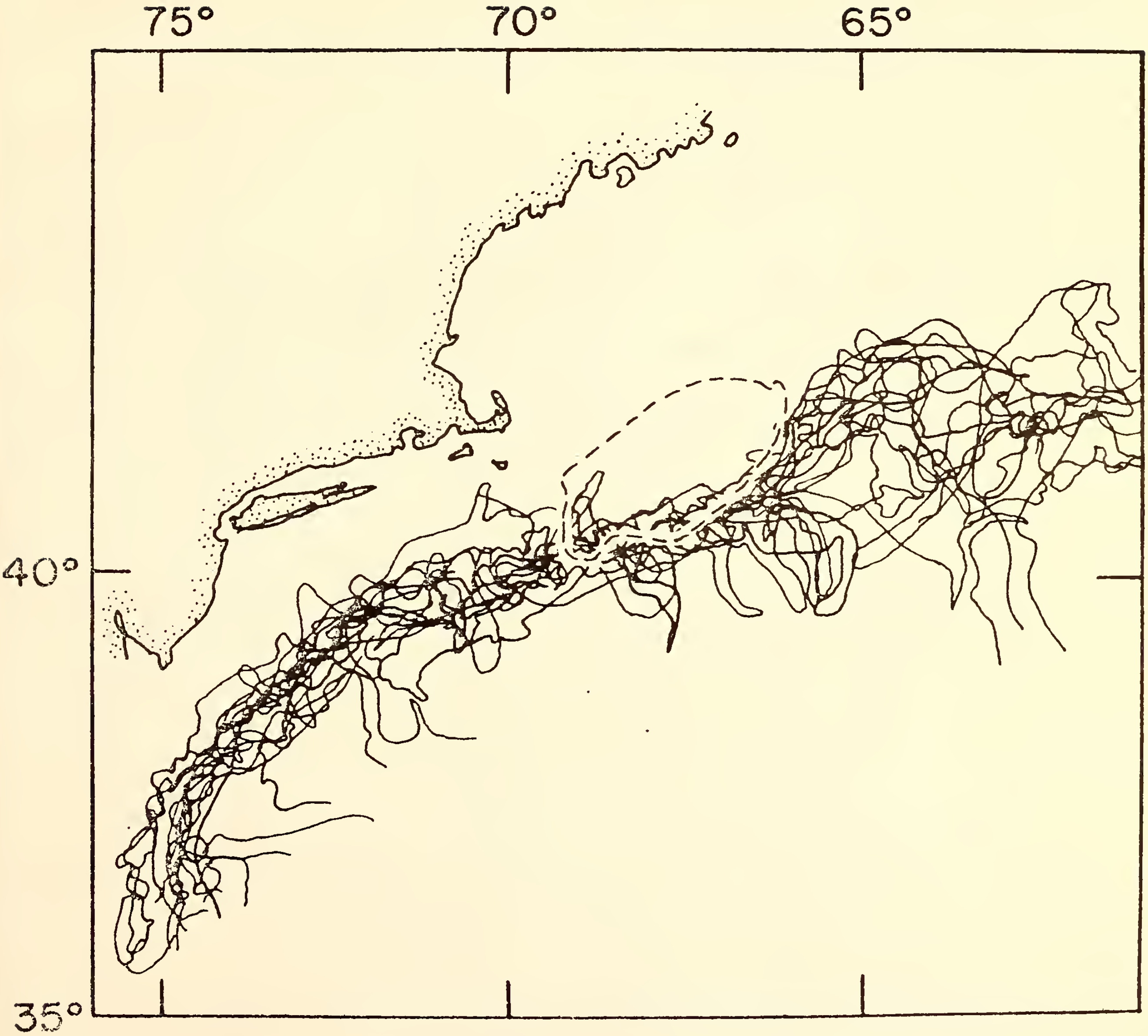
13.9 Drift buoy trajectories 9-17 October, 1957.



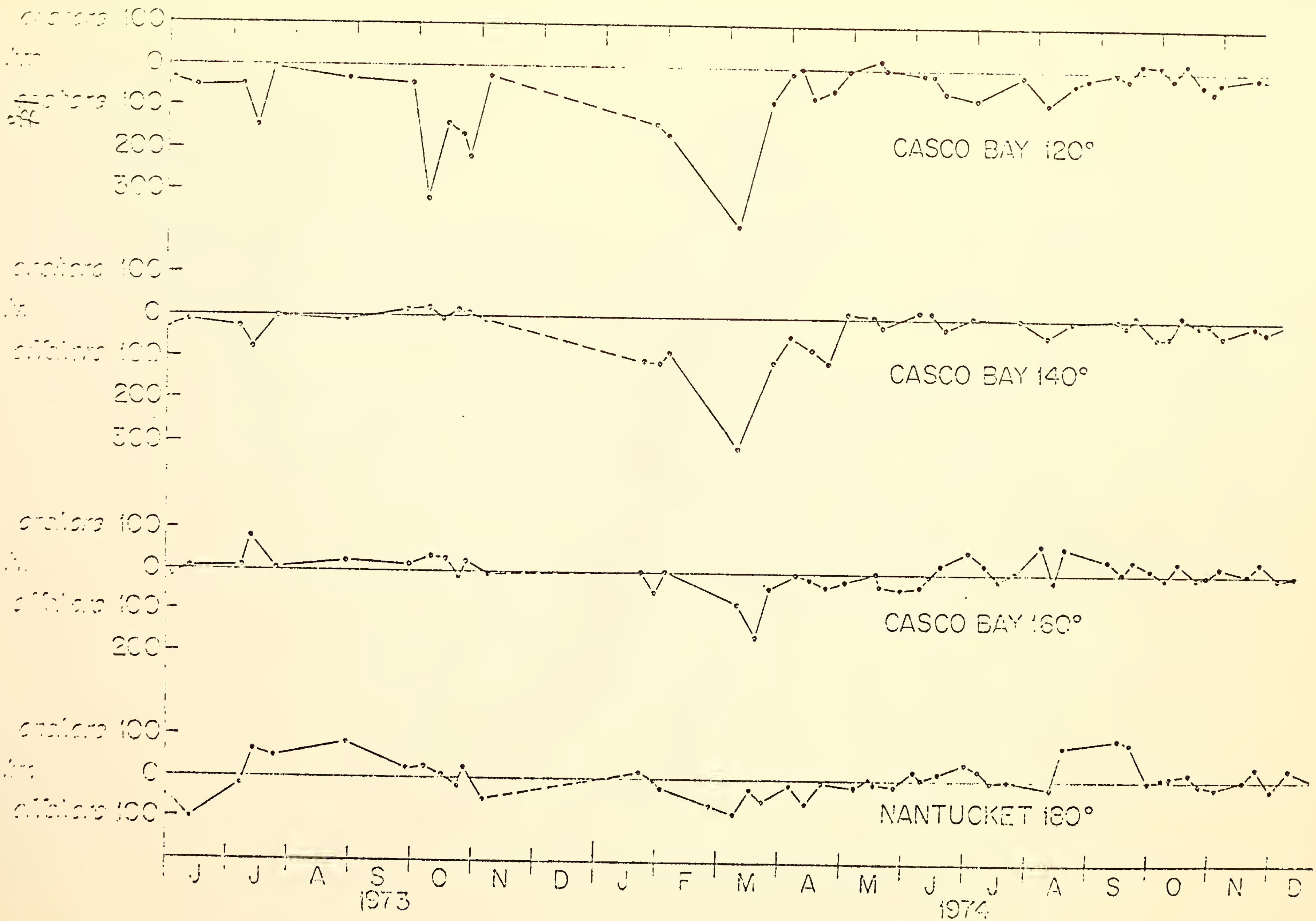
13.10 Drift buoy trajectories December 1957.



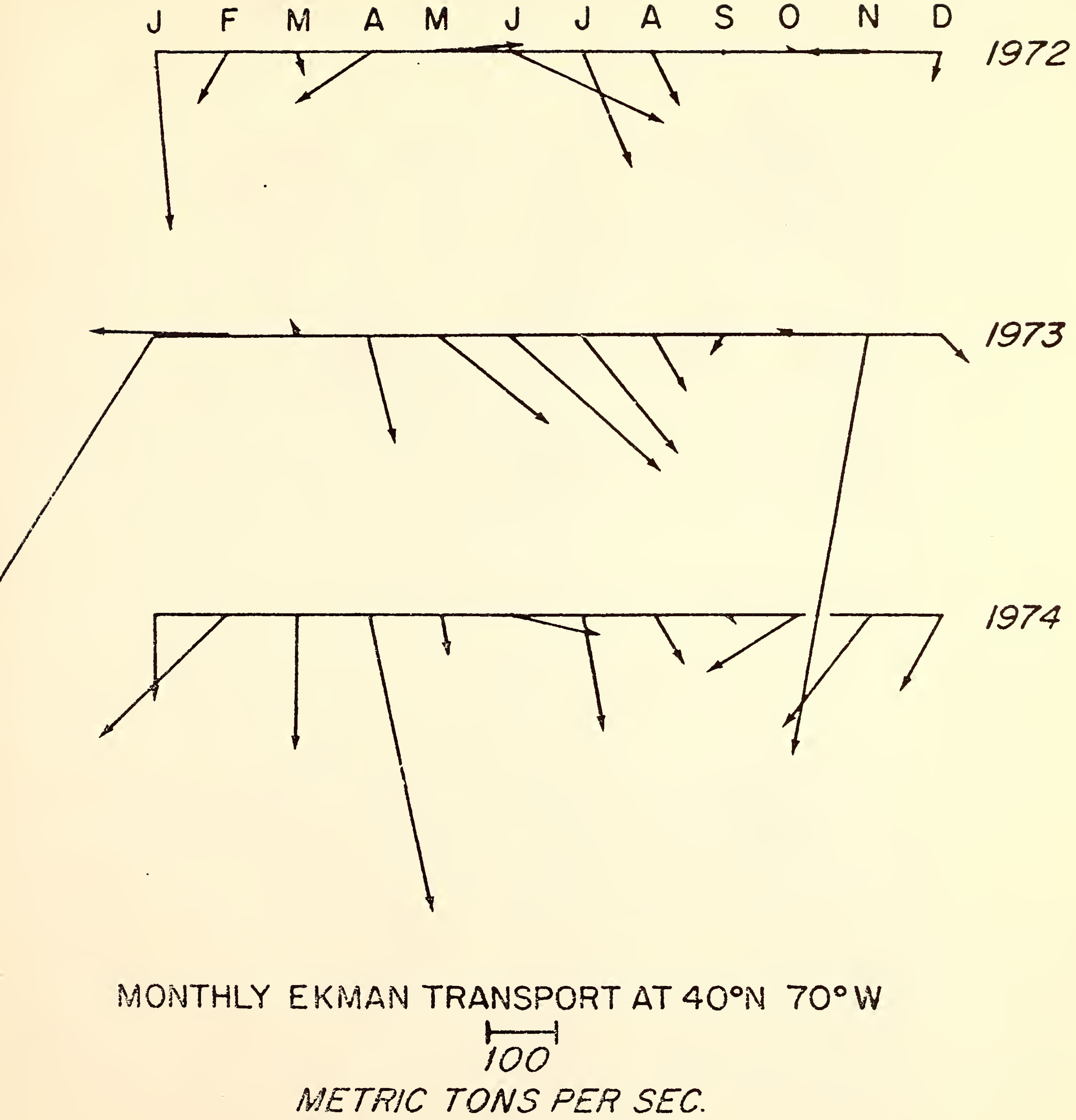
13.11 Example of weekly frontal chart produced by National Environmental Satellite Service, NOAA, with standard lines along which fronts were measured superimposed.



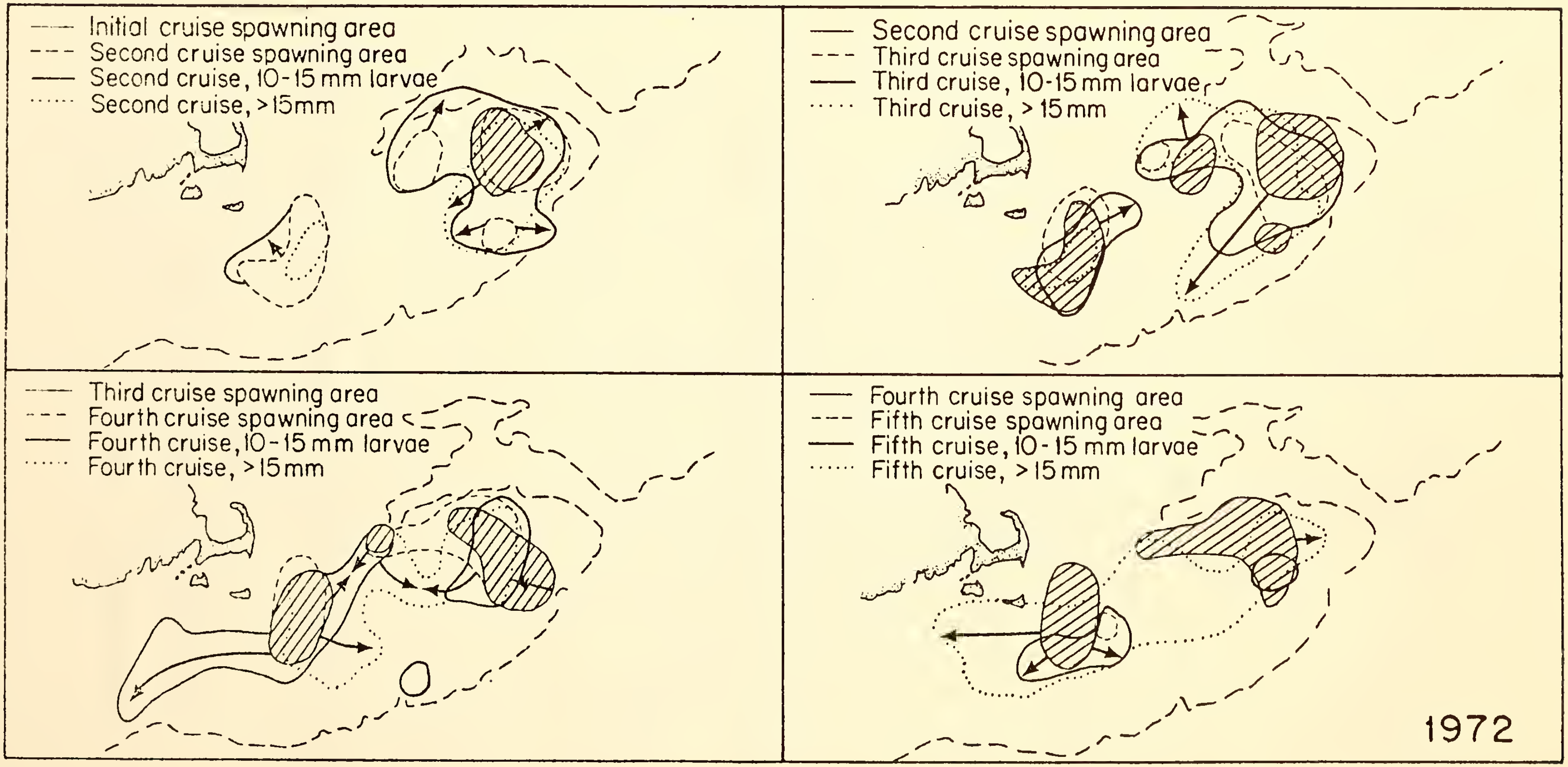
13.12 Frontal positions as reported during September to December 1973 and 1974.



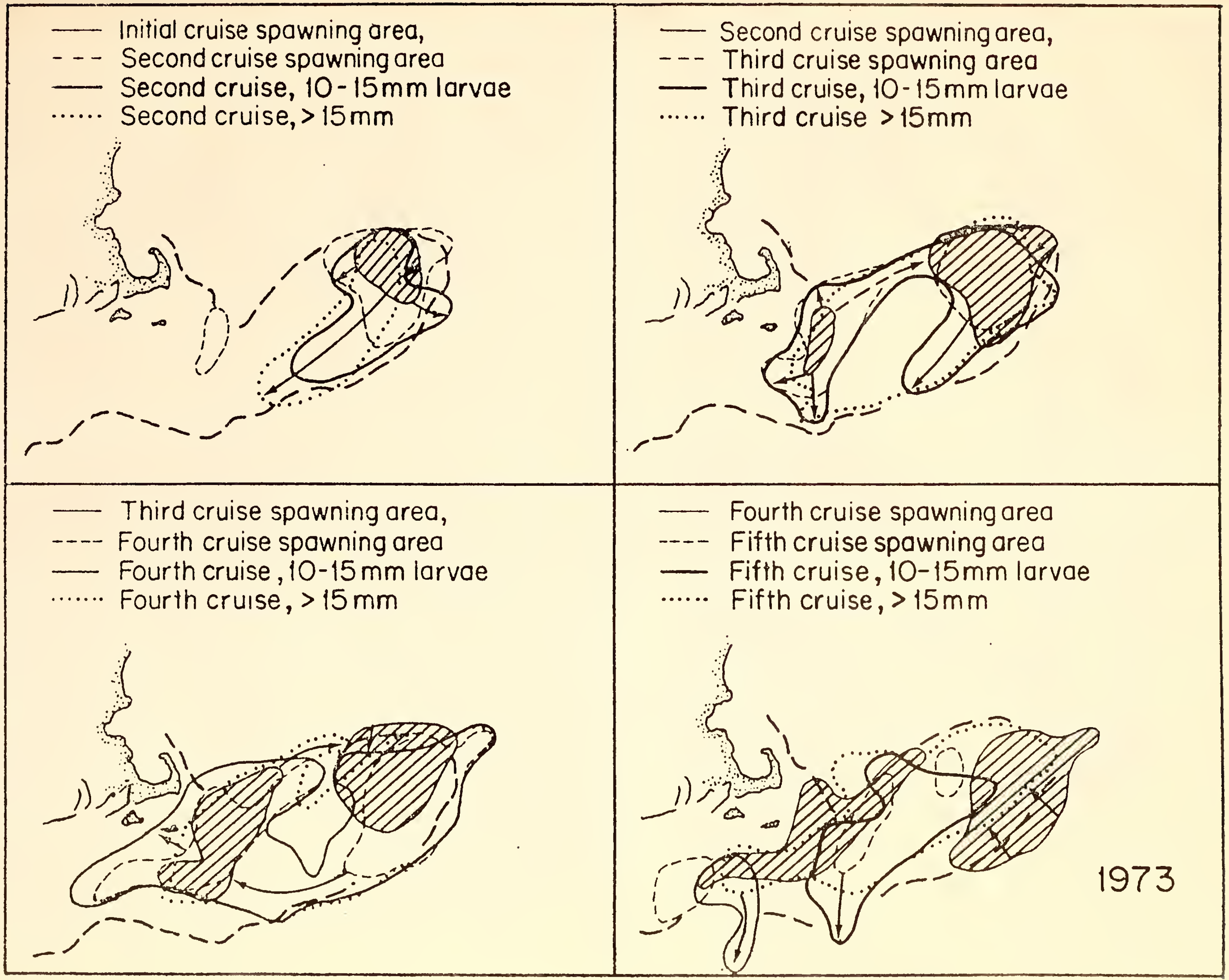
13.13 Temporal variation of the position of the Shelf Water front relative to the edge of the Continental Shelf along the indicated azimuths. Positive values are shoreward from the



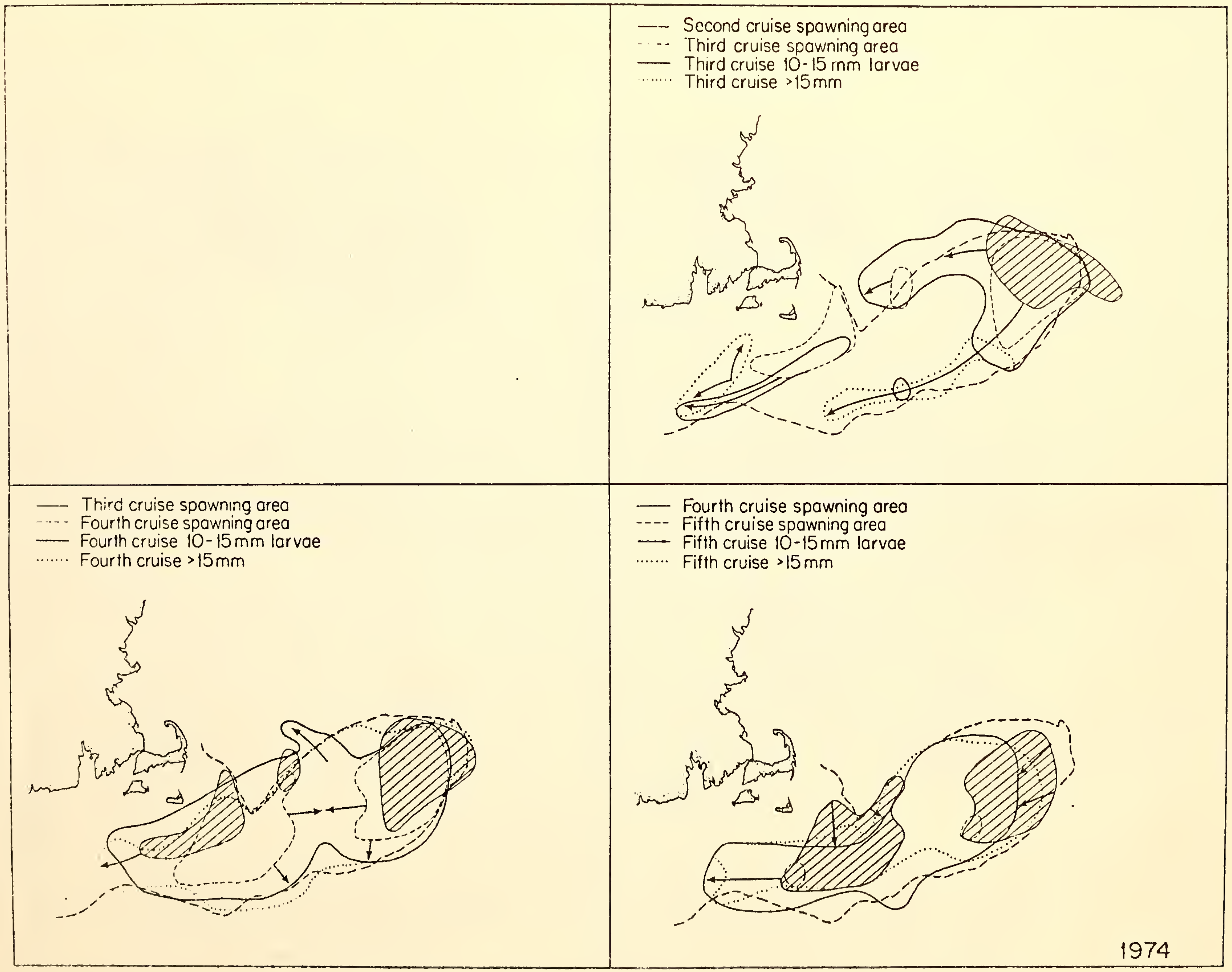
13.14 Monthly Ekman Transport at 40°N-70°W for 1972-1974.



13.15 Locations of various length herring larvae relative to previous cruises in 1972.



13.16 Locations of various length herring larvae relative to previous cruises in 1973.



Second cruise spawning area
Third cruise spawning area
Third cruise 10-15 mm larvae
Third cruise >15mm
Third cruise spawning area
Fourth cruise spawning area
Fourth cruise 10-15mm larvae
Fourth cruise >15mm
Fourth cruise spawning area
Fifth cruise spawning area
Fifth cruise 10-15mm larvae
Fifth cruise >15mm
1974

WIND-DRIVEN TRANSPORT
ATLANTIC COAST AND GULF OF MEXICO

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Resource species which are planktonic during their early life stages are dependent upon weather and ocean circulation for environmental conditions appropriate for their survival and development. This is especially true for those organisms whose early stages are planktonic in the surface layer for longer periods. Currents generated by local winds can transport larvae in the surface layer toward or away from nursery areas, while at the same time the temperature of the surface water mass may be rapidly changed because of the wind's action on it.

An example of the influence of wind-driven transport on larval survival, recruitment and year class strength can be found in the Atlantic Menhaden. Winter spawning of this species takes place south of Cape Hatteras at some distance off shore, near the edge of the Gulf Stream. Eggs and larvae from this spawning activity are transported toward estuarine nursery grounds, under favorable conditions, by wind-driven currents in the surface layer. Studies of monthly Ekman (wind-driven) transport and recruitment have revealed a strong link between years of high or low recruitment and years of strong or weak westward Ekman transport during Jan-March for the years of 1955-70. A model relating these factors shows that variations in Jan-March zonal Ekman transport at a point south of Cape Hatteras accounts for about 60% of the variation between actual and expected (density-dependent) recruitment.

It is anticipated that variations in Ekman transport are significant in the larval survival, recruitment and year class strength of resource species other than Atlantic menhaden. We hope that NMFS fishery biologists will see other possible applications of this environmental data base and initiate cooperative studies of such relationships.

Estimates of wind-driven (Ekman) transports in the upper layer of the North Atlantic Ocean and Gulf of Mexico are among the suite of parameters computed from monthly average atmospheric pressure charts by the Pacific Environmental Group (PEG). The parameters are made available on alternate five-degree printed grids within 30 days of the end of the month portrayed. The computational method employed is described by Bakun in NOAA Technical

Report NMFS SSRF-671 (1973). In addition to this coarse grid, PEG will produce, upon request, a three-degree print-out and plots of monthly or quarterly parameters vs. time for any selected grid point. The monthly transports and related parameters are available back to 1946. For further information regarding these data, contact Chief, Atlantic Environmental Group, National Marine Fisheries Service, RR 7A, Box 522-A, Narragansett, R.I. 02882 (Phone 401-789-9326) or Chief, Pacific Environmental Group, National Marine Fisheries Service, %Fleet Numerical Weather Central, Monterey, California 93940 (Phone 408-373-3331).

Comparison of the 1974 estimates (figs. 1, 3) with 10-year (1964-73) mean values (figs. 2, 4) revealed several possibly significant variations.

40°N, 70°W: The January-May period of southwestward transport (10-year mean) showed an usually weak westward component in January and an ususually strong southward component in April, 1974. The later condition should have carried the Shelf Water/Slope Water front farther from Georges Bank than normal, a condition which indeed was detected by infra-red scanners on the NOAA-2 satellite during mid April (see section 17 of this report). At this time (April 12) the front was found to be 60 Km seaward from the edge of the Georges Bank Shelf (100 fm isobath) south of Nantucket, but its average position during 1974 was 0.6 Km shoreward of the shelf edge. This was the second largest seaward excursion (first: 61 Km, Jan 22-24) of the front observed south of Nantucket in 1974.

The period of southeastward transport in May-August was weaker in 1974 than the 10-year average, except for July which was comparable. The transport in June contained larger eastward and smaller southward components than the 10-year average. The unusually weak southward component in August corresponds with the advance of the Shelf Water-Slope Water front on southern Georges Bank, as detected by satellite infra-red imagery.

October 1974 was a period of much stronger southwestward transport than the 10-year average condition, which is one of very weak transport.

35°, 75°W: Estimates of monthly average Ekman transports at this point have been used successfully in the study of variations in menhaden recruitment along the U.S. Atlantic coast, because they describe the intensity of shoreward transport of water carrying eggs and larvae of menhaden in the winter spawning area south of Cape Hatteras. Conditions for shoreward transport of larvae were poor during January-March of 1974. The westward component present in the 10-year mean values during those months was missing in January and March, and weak in February 1974. During January the zonal transport was 70 metric ton/sec/km eastward, counter to the direction desired for shoreward larval transport, and in February it was 70 metric tons/sec/km westward. Good years for larval transport in the past have shown westward transports during January and February with values in excess of 500 metric tons/sec/km. It is anticipated that larval survival and recruitment in 1974 would be low and this condition will be reflected in the year class strength.

30°N, 80°W: During January and February 10-year average transports at 30°N, 80°W show westward components, as was the case at 35°N, 75°W. In 1974 there was an eastward component instead in January and only a very weak westward component in February, similar to the pattern at 35°N, 75°W.

In the spring and summer period (March-August) the 10-year average transport values show a small eastward component, usually combined with a small northward component. In 1974 the eastward components were present, but the northward components generally had been replaced by small southward components.

During October 1974 an unusually strong transport to the NNW occurred. This condition should have led to close approach of oceanic waters to the coast and a strong along shore current toward the NNE along the northern Florida and Georgia coast.

27°N, 84°: The 10-year mean pattern of monthly Ekman transport at this position in the eastern Gulf of Mexico shows strong fall and winter transports to the NNW-NNE. In the spring and summer period (March-August) the transports are smaller in magnitude and contain more pronounced eastward components (onshore for the west coast of Florida). Transport conditions in 1974 differed considerably from the mean, mainly in magnitude, but also in direction in some months. The most apparent difference was the extremely strong transport toward the NNW in October. The direction of the transport is 20°farther toward the west than the direction of the 10-year mean transport for October, but the magnitude was about 2 1/2 times as great as the mean, which should have led to stronger alongshore transport along the western coast of Florida. The transport value forNovember 1974 was only slightly greater than the 10-year mean and was close to the average direction; conditions had returned to normal by them. The coastal effects of the unusual transport condition in October should have been: (1. along the west coast of Florida: strong alongshore (NNW) flow of warmwater (2. along the zonal coast of Mississippi, Alabama and northern Florida: stronger westward currents displacing pelagic species toward the Mississippi Delta and closer approach of water of Caribbean origin in the East Gulf Loop Current.

27°N, 90°W: At this position the most outstanding variation from the 10-year mean was very strong transport to the NNW in October very similar to the condition observed at 27°N, 84°W. In the coastal waters west of the Mississippi Delta this anomalous transport would result in stronger alongshore (westward) currents and closer approach of water characteristic of the central Gulf.

Another anomalous condition which existed at this position in 1974 was the lack of the westward component typically found in the transports in January and February. Instead, the transport in January 1974 had a strong eastward component and that in February was very weak with a neither eastward nor westward components. This condition should have manifested itself in January in coastal waters west of the Mississippi Delta as a reversal in usual alongshore currents, eastward instead of westward. In February the alongshore currents should have been weak and variable, due to the absence of any prevailing zonal component in the Ekman transport that month.

27°N, 96°W: The most apparent anomaly in Ekman transport at this position during 1974 was the strong NNW vector during September instead of the weaker NNE vector of the 10-year mean condition. This condition should have lead to close approach of central Gulf water to the coast and weaker-than-usual northeastward alongshore currents during the month.

The abnormally strong NNW transports at the other two positions in October 1974 were not evident at this position. Instead, a NNE transport about twice the magnitude of the average NNW value was evident.

The mean spring and summer transports to the northeast were weaker and directed more to the NNE in 1974. This condition should have led to an alongshore current that was weaker than usual.

MONTHLY AVERAGE EKMAN TRANSPORTS FOR SELECTED POINTS OFF THE U.S. EAST COAST AND IN THE GULF OF MEXICO
(In metric tons/sec/km) (+ Eastward and Northward)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<u>40°N, 70°W</u>												
Zonal	0	-190	- 10	90	10	120	30	40	10	-130	-120	- 60
Meridional	-130	-180	-200	-430	- 60	- 40	-170	- 70	- 10	- 80	-160	-110
<u>35°N, 75°W</u>												
Zonal	70	- 70	40	120	50	120	50	40	- 10	-240	-110	- 20
Meridional	-110	-270	-190	-360	- 60	- 50	-100	- 10	30	150	-150	-170
<u>30°N, 80°W</u>												
Zonal	110	- 10	70	60	100	90	50	80	10	-470	-120	0
Meridional	40	-100	- 80	- 10	- 10	- 10	- 10	100	230	810	130	- 10
<u>27°N, 84°W</u>												
Zonal	210	- 30	40	130	140	50	20	90	30	-980	-300	- 30
Meridional	470	50	80	450	130	40	20	330	430	1860	820	200
<u>27°N, 90°W</u>												
Zonal	430	0	260	560	470	50	10	180	10	-650	-270	- 10
Meridional	830	160	440	990	620	350	90	460	840	1820	840	260
<u>27°N, 96°W</u>												
Zonal	- 60	150	780	650	620	430	380	510	-370	170	- 40	90
Meridional	780	270	790	890	710	630	400	660	900	880	580	370

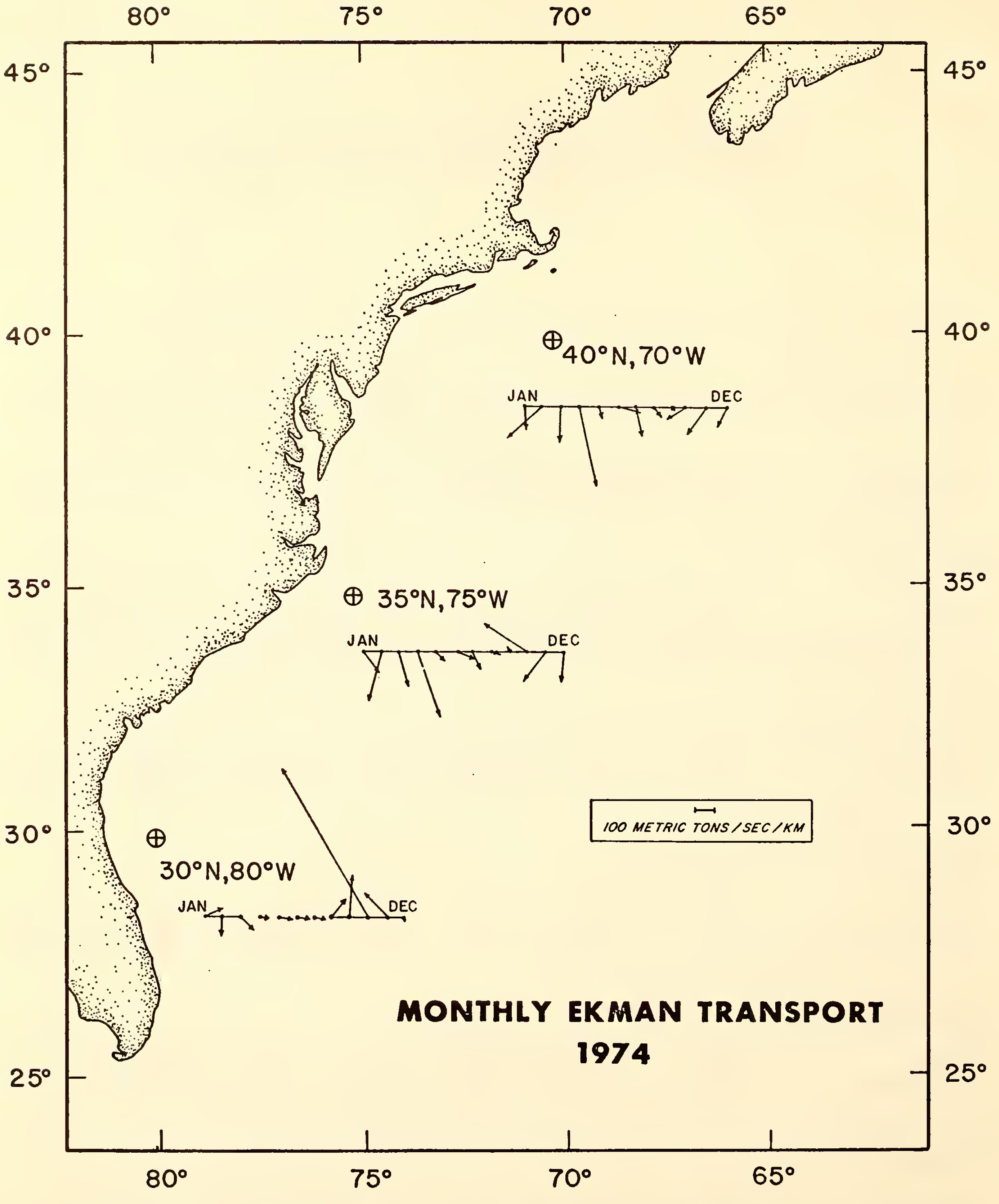

Figure 14-1. Monthly Ekman (wind-driven) transports for three positions off the Atlantic Coast for 1974.

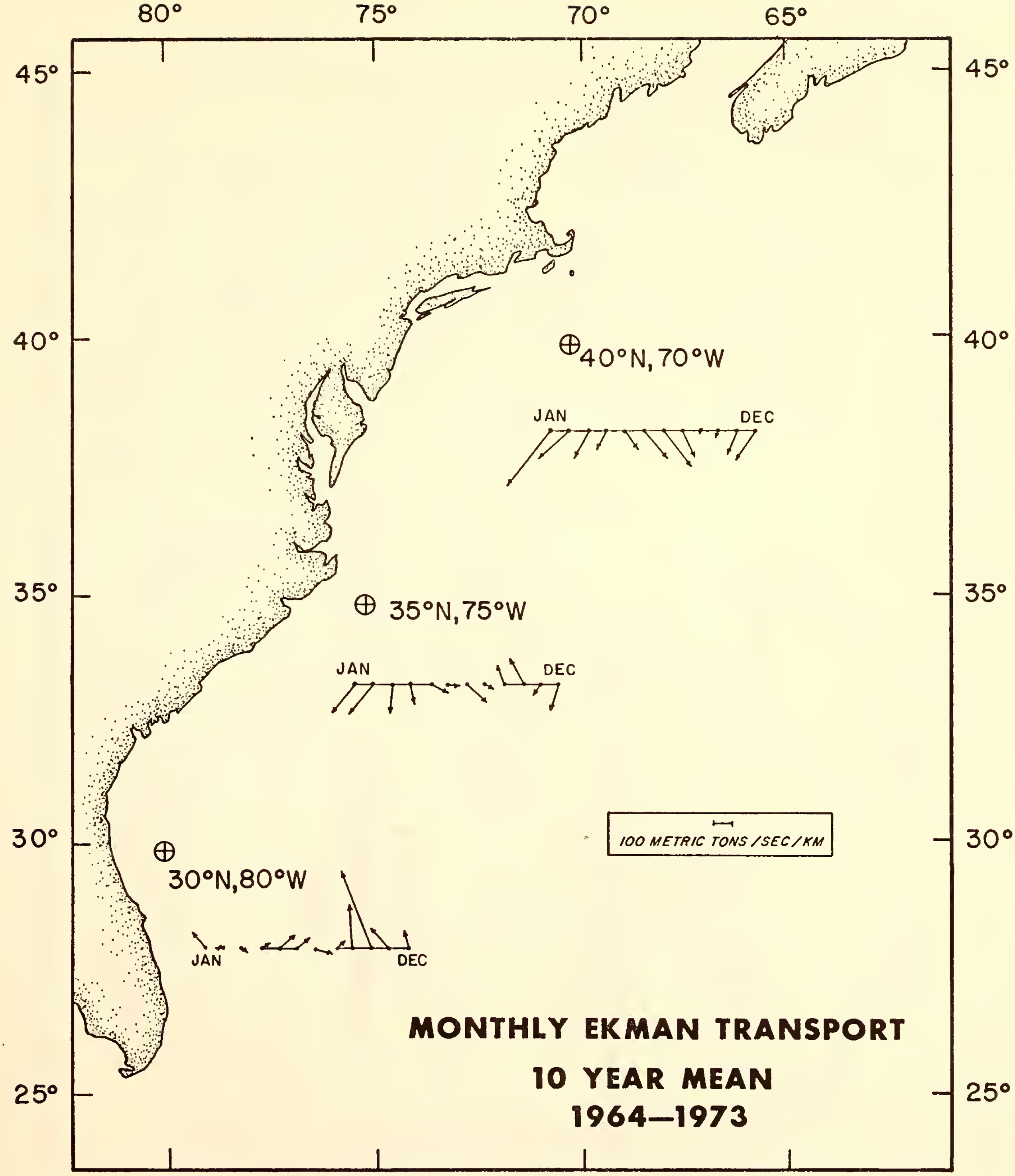

Figure 14-2. Mean monthly Ekman (wind-driven) transports for three points off the Atlantic Coast for the 10-year period of 1964-73.

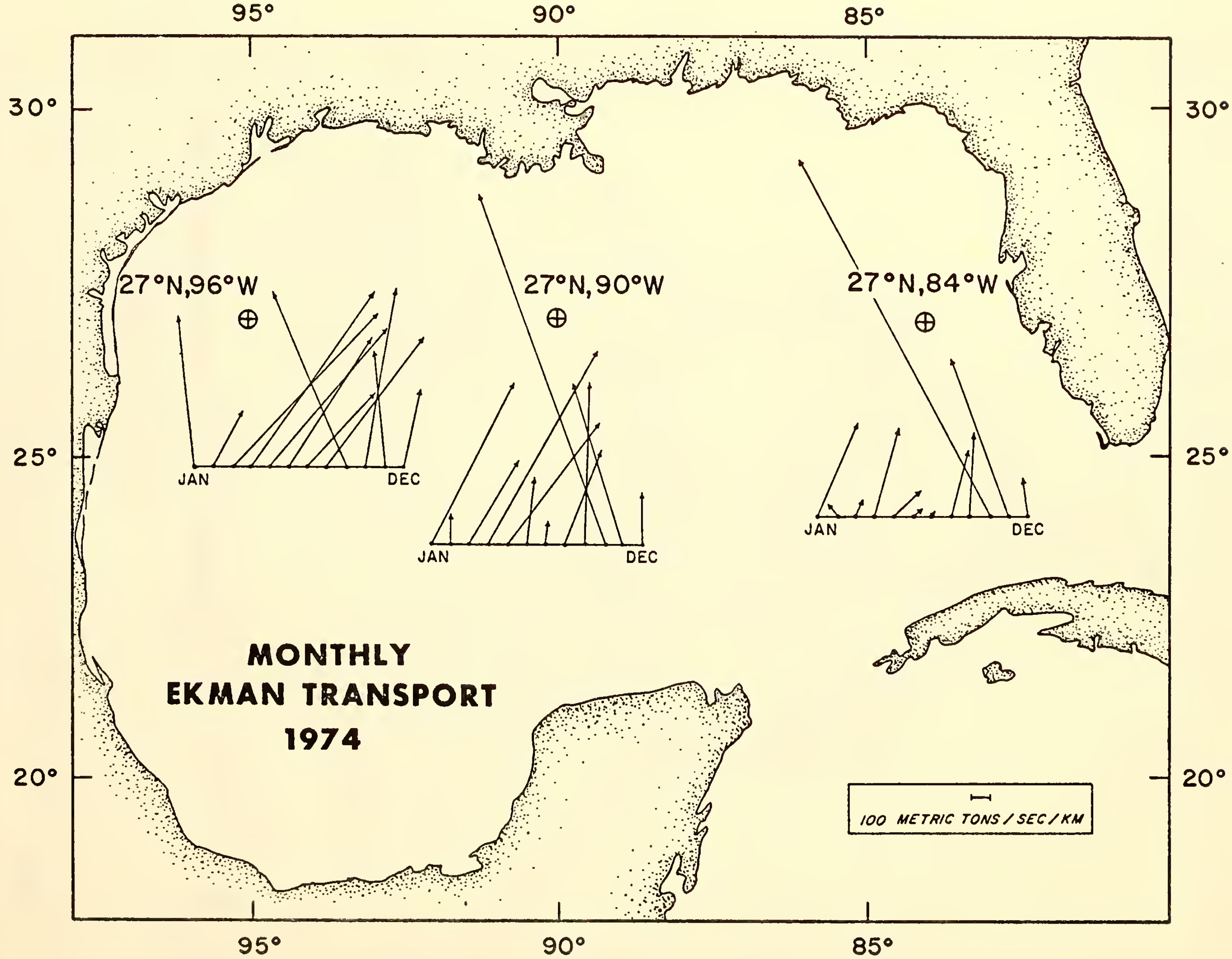

Figure 14-3. Monthly Ekman (wind-driven) transports for three points in the northern Gulf of Mexico for 1974.

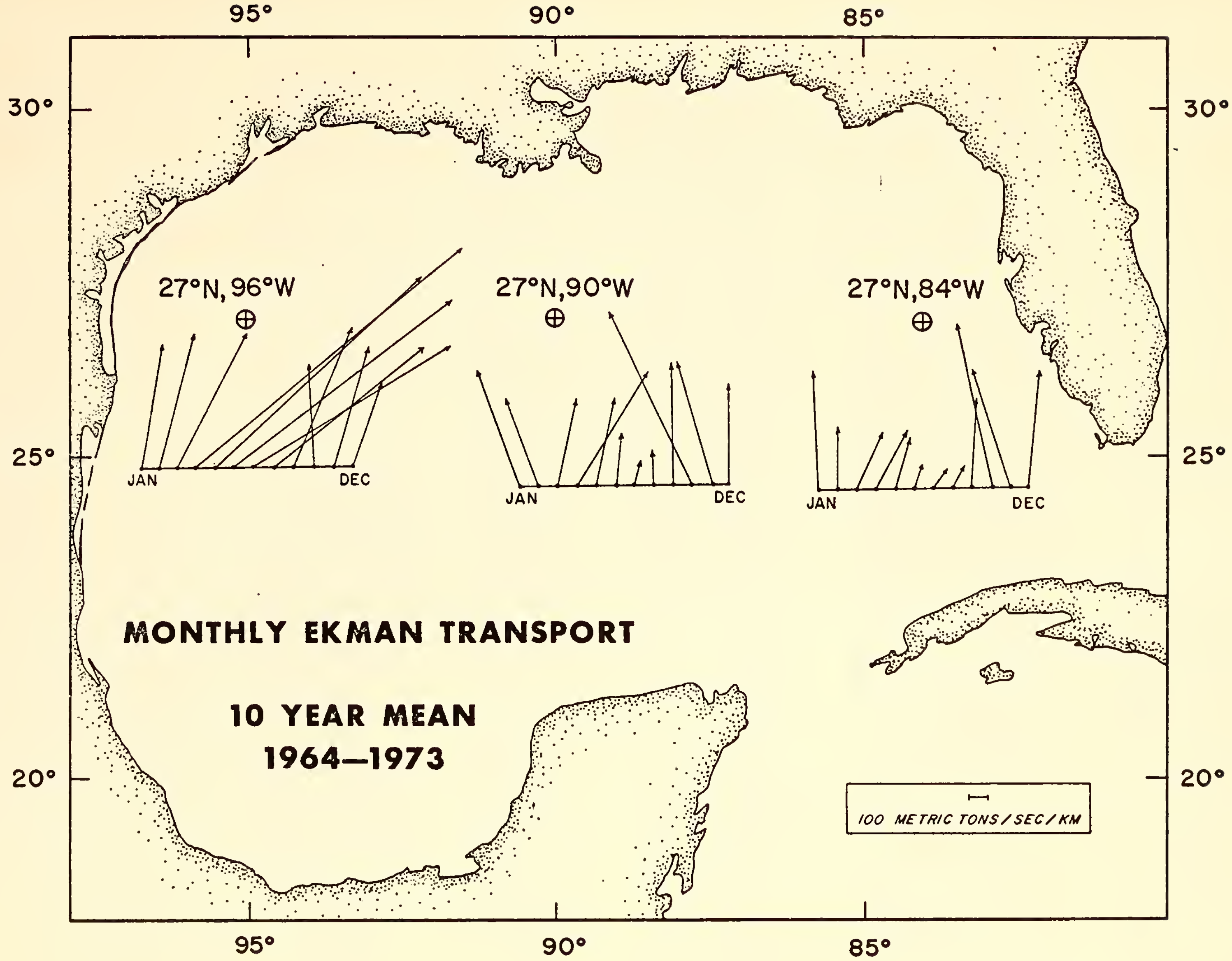

Figure 14-4. Mean monthly Ekman (wind-driven) transports for three points in the northern Gulf of Mexico for the 10-year period of 1964-73.

SEA-SURFACE TEMPERATURE ANOMALIES AT SHORE STATIONS IN THE GULF OF MAINE DURING 1970-74

J. Lockwood Chamberlin and John J. Kosmark

Atlantic Environmental Group

As a means of determining temperature trends in the Gulf of Maine during 1974, in relation to the long term record as well as to the immediately preceding years, anomalies of mean monthly temperature have been calculated from the records for 5 shore stations for the years 1970 - 74. The anomalies are based on averages of the monthly means for the years 1950 - 59 (Figure 1). Use of this base period follows Stearns (1964), who published anomaly graphs for 27 shore stations along the Atlantic coast of the United States for the entire historic record up to 1961.

Stearns (1965) pointed out that the base period 1950 - 59 coincides rather closely with the years of maximum warming of sea-surface temperature during this century along the Atlantic coast north of Cape Hatteras. In consequence, the anomalies he computed from this base tended to have a negative bias throughout most of the first half of the century. The anomalies for 1970 - 74 continue to show this bias at some of the Gulf of Maine stations.

The monthly mean data from 4 of the Gulf of Maine stations for 1970 - 74 were obtained from the NOAA National Ocean Survey. The data from an additional station, Boothbay Harbor, were obtained from the Maine Department of Marine Resources, by Ronald Schlitz, Northeast Fisheries Center, NMFS.

Viewed collectively, the anomaly records for the 5 stations (Figure 1) reveal neither a coherent temperature pattern in 1974 nor a clear trend during the 5 year period. Indeed, the lack of coherence among the stations during these years, in contrast to the considerable coherency among them in the earlier part of this century (Stearns, 1964, 1965), is sufficiently puzzling to warrant further investigation.

References

Stearns, F., 1964. Monthly sea-surface temperature anomaly graphs for Atlantic coast stations. U.S. Fish Wildlife Serv. Spec. Sci. Rept. Fisheries, No. 491, 2 p., 1 fig., 10 pls.

Stearns, F., 1965. Sea-surface temperature anomaly study of records from Atlantic coast stations. Jour. Geophys. Res. 20, No. 2, pp. 283 - 296.

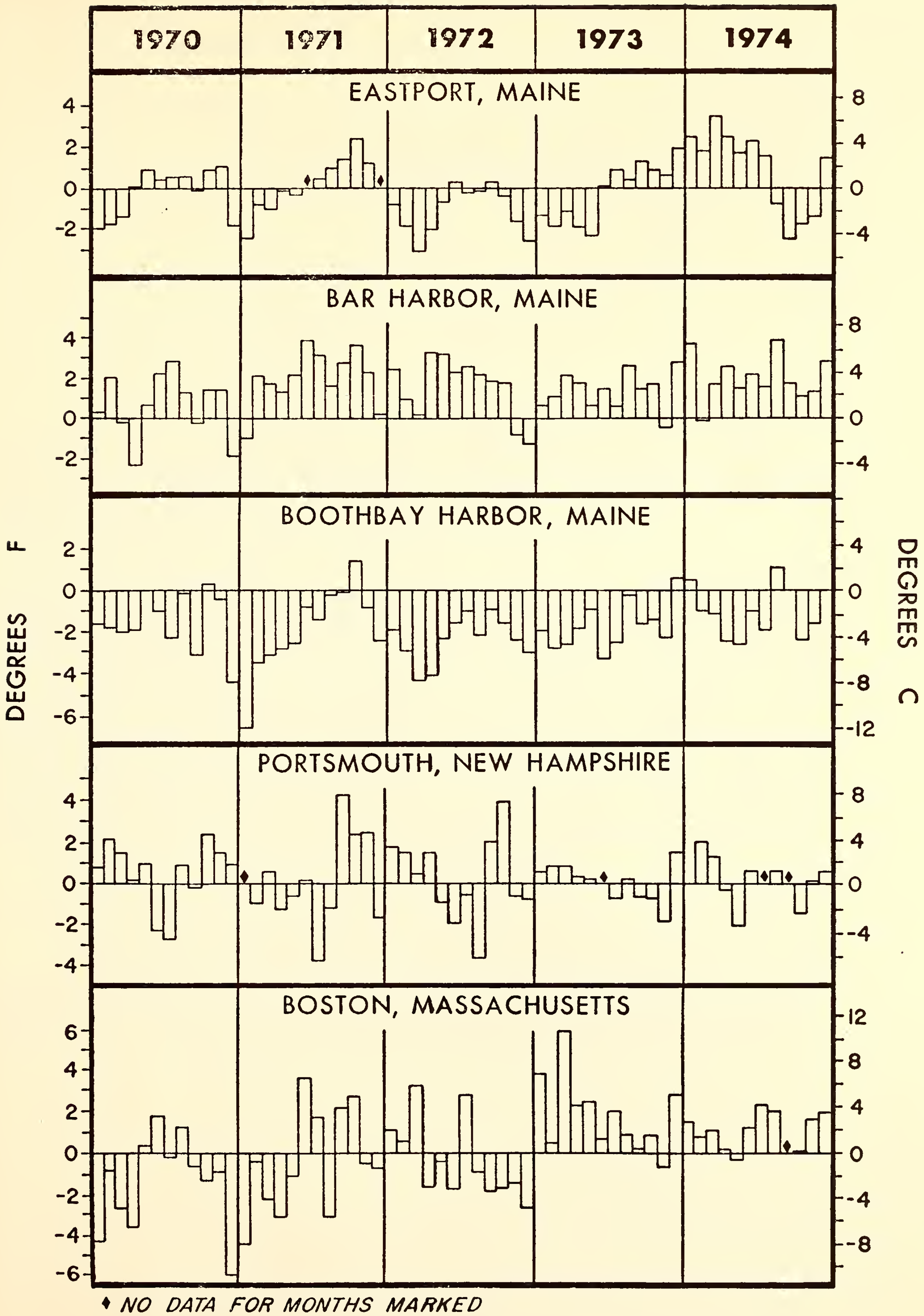

Figure 15.1 Monthly sea-surface temperature anomalies at shore stations in the Gulf of Maine for 1970 - 74, based on 1950 - 59 averages.

SEA-SURFACE TEMPERATURES ANOMALIES GULF OF MAINE AND GEORGES BANK-NANTUCKET SHOALS REGION DURING 1970-74

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Atlantic Environmental Group

Monthly sea-surface temperature anomaly trends in the offshore waters of 1) the Gulf of Maine and 2) over Georges Bank and Nantucket Shoals are diagrammed in Figure 1 for the years 1970-1974. The diagram is based on one degree square anomaly values published in the Gulf Stream Monthly Summary, U.S. Naval Oceanographic Office.

Initial consideration of the annual trends of the anomalies for several of the squares revealed missing values for many of the months, largely because of an insufficiency of sea-surface temperature data. Furthermore, the little coherence in the anomaly trends among even those of the squares with the most nearly complete records indicated that, at best, the data base was sufficient for only region comparisons. Accordingly, anomalies were calculated for the Gulf of Maine and the Georges Bank-Nantucket Shoals regions by averaging the values for 7 different squares in the former region and 5 squares in the latter (see map in Figure 1). Each of the squares selected for this averaging has at least the majority of its area within the region to which it is assigned and has anomaly values available for more than 60 percent of the 60 month period considered.

Coherence between the regions is high during the overall 5 years; for example, opposite anomaly signs occur in only 15 (25%) of the months.

The pattern of anomalies during 1974 presents no striking contrast to the previous 4 years in either region. During 1974, and to a major extent during all 5 years, the anomalies in both regions are strongly positive in the winter and autumn, whereas, in the spring and summer, they are often negative, but generally not far below the normal.

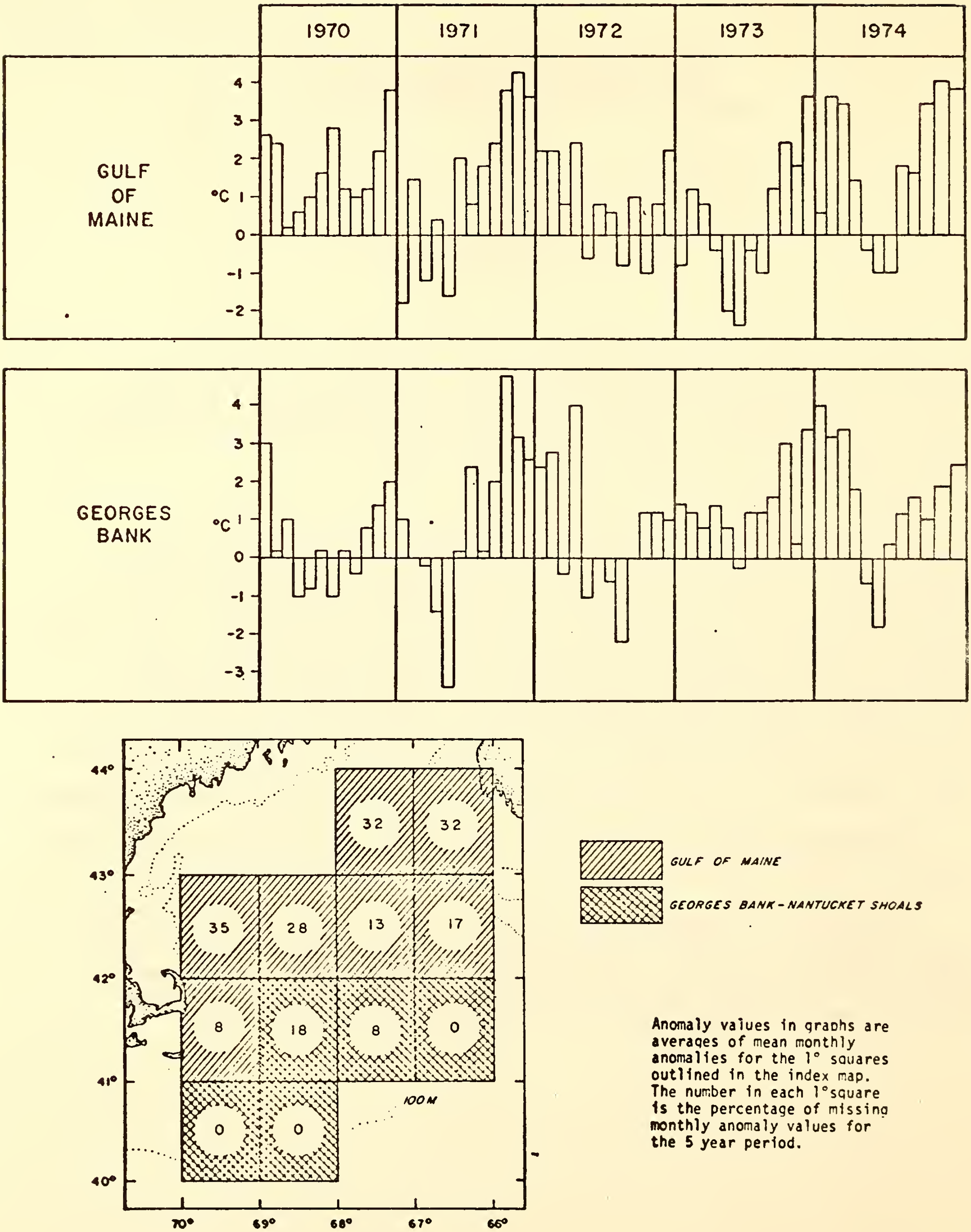

Figure 16.1 Monthly sea-surface temperature anomalies for the Gulf of Maine and the Georges Bank-Nantucket Shoals regions during 1970 - 74.

VARIATIONS IN THE SHELF WATER FRONT OFF THE ATLANTIC COAST BETWEEN CAPE HATTERAS AND GEORGES BANK

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Using charts of sea surface temperature fronts prepared by the National Environmental Satellite Service (NESS) and collaborative data from ship-of-opportunity XBT drops, scientists of the Atlantic Environmental Group (AEG) are working to monitor and analyze the position of the Shelf Water front as an aid to determining the relationship between this feature and pelagic and demersal fishery stocks over the continental shelf and slope.

The variation in the location of the Shelf Water front is certain to have a short-term effect on the distribution and may have a longer-term effect on the abundance of resource species. The convergence zone which is associated with any persistent surface front acts to accumulate living and non-living particulate materials in the surface layer, which in turn will attract food chain organisms, including pelagic climax predators such as tunas, swordfish, and sharks. Fisherman in search of these species may find information concerning the front's whereabouts quite useful in developing more efficient fishing strategy.

With the knowledge that the front may extend to the bottom over the continental shelf, as revealed by XBT transects, we anticipate that the variation of the front's position should influence the distribution of epi-benthic organisms also, and knowledge of the front's position could be useful in the strategy employed in harvesting demersal species.

In addition to contributing to the development of more efficient harvesting strategies, knowledge of the variation of the position of the Shelf Water front can help explain changes in water mass characteristics in spawning and nursery areas and the consequent variations in recruitment and year-class strength. Satellite surveillance of the front's position and configuration during critical periods in the early life history of resource species could provide information useful in making predictions of their year-class strengths.

The interface between the cool, low-salinity Shelf Water mass and the warmer, higher salinity Slope Water mass, or occasionally with the still warmer and more saline Gulf Stream water, off the Atlantic Coast of the United States frequently is expressed at the sea surface as a thermal front, the Shelf Water Front. The front can be observed by satellite-borne infra-red radiometers, clouds permitting, and the National Environmental Satellite Service of NOAA has been plotting the position of this front on charts made available to the public at about weekly intervals since June 1973 (example fig. 1). The observations are made by a very High Resolution Radiometer on the NOAA II (recently NOAA IV) Satellite, which senses radiation in the 10.5-12.5 μ m range and has a resolution of about 1 km at nadir. The charts of the coastline and oceanic thermal features are drawn either from the best image of the week or a composite of several. The completed charts are sent to a mailing list of users and transmitted by facsimile to National Weather Service stations in the Atlantic coastal area.

One effort at AEG to portray the temporal variation of the Shelf Water Front is based on a plot of measured distances to the front along standard bearing lines from selected coastal points (fig. 2). The results of these measurements for the period of June 1973 - December 1974 are shown in Figures 4 - 16. The distances portrayed are measured from each satellite chart individually to remove the error (ca 5%) introduced by variations in scale from chart to chart. The chart distances (in mm) are converted to real distances (in Km) then are diminished by the distance along each bearing line to the edge of the continental shelf. The resulting values represent distance from the shelf edge to the front, positive values seaward and negative values shoreward from the shelf edge.

The magnitude of variation in frontal position generally increases progressing northward from the Albemarle Sound transect to the Casco Bay transects. This is also apparent from the composite plot of all the observed frontal positions (fig. 3). In spite of this wide variation the average position of the Shelf Water front lies rather near the edge of the continental shelf, from Cape Romain to the "northeast corner" of Georges Bank.

Since the available data span only 18 months, it is impossible to sort out "normal" annual variations in the position of the Shelf Water Front. However, some information can be gleaned from a determination of the annual mean and standard deviation of the frontal position relative to the edge of the shelf on each of the bearing lines for 1974, as follows:

Bearing Line		Sample Size	Mean Separation (km) + = seaward	Standard Deviation
Casco Bay	120	30	45.4	70.9
Casco Bay	140	31	35.4	64.0
Casco Bay	160	36	6.1	39.3
Nantucket	180	37	- 0.6	38.5
Montauk	150	34	19.8	36.7
Sandy Hook	130	36	1.2	46.8
Cape May	130	38	4.1	31.8
Cape Henry	95	40	17.4	36.4
Albemarle Sd.	90	40	-11.5	24.6
Cape Lookout	135	24	-18.2	20.1
Cape Fear	140	19	-20.2	40.5
Cape Romain	140	21	- 9.9	43.4

The mean position of the front was seaward from the edge of the continental shelf on all but five bearing lines by distances ranging from 1.2 to 45.4 km. On the five bearing lines on which the mean frontal position was shoreward from the shelf edge the separations were small, ranging from 0.6 to 20.2 km. The variability of the front's position, as indicated by the standard deviation, is high on all bearing lines, ranging from 20.1 to 70.9 km. The lowest variability was found in the southern area on the Cape Lookout 135 line and the highest on the northernmost (Casco Bay 120), but the progression of values between these extremes was not regular.

A major excursion of the front seaward from Georges Bank (Nantucket, Casco Bay lines) occurred early in 1974 (figs. 4-6), with a maximum in early March, with separations in excess of 300 km from the edge of the continental shelf. At this time there were two large eddies, one warm core, the other cold, in the vicinity of the front's usual position, possibly resulting from the storm conditions which obscured the area most of February. Also, during March the southward Ekman (wind driven) transport of surface water reached its largest value of the year (see Wind-Driven Transport section of this report).

Other major seaward excursions in 1974 occurred on the Cape Henry bearing line in early July, Cape May line in August and Sandy Hook line in January and early February.

Observations of the position of the shelf water front south of Cape Hatteras were limited to winter, spring and fall months, because of cloud cover during the summer months. Along each of the three bearing lines, the front's position was shoreward of the edge of the continental shelf, except for January-February and occasional seaward excursions in the spring months.

Significant shoreward excursions of the Shelf Water front occurred on the Casco Bay 160° and Nantucket 180° transects in August, with magnitudes of about 50 km and 100 km respectively. During this period, (late August) Slope Water invaded Georges Bank until about 14% of it was covered by this water mass (fig. 16). In early September the invasion continued along the southern edge, as indicated by the shoreward excursion of the front along Nantucket 180°, leading to almost 18% coverage of the bank by Slope Water early in the month, decreasing to about 4% by the end of the month. At no time during the year did the invasion of the bank by Slope Water exceed 18% and the average coverage for the year was 3.5% with a standard deviation of 4.8%, based on a sample of 30 observations. The error possible in the determination of the area of the bank covered by Slope Water is estimated to be 10-15% of the area of coverage.

During August and September, when the Slope Water mass overlapped Georges Bank the most, the southward component to Ekman (wind-driven) transport of the surface layer was low; the September value was the lowest for the year (see section 14 of this report). This observation and the earlier one of the coincidence of strong southward Ekman transport with offshore excursions of the Shelf Water front suggest the position of the front in the southern region of Georges Bank is directly influenced by wind-driven transport of the upper layer.

Several attempts have been made to verify the locations of the Shelf Water front on the satellite charts by comparison with positions obtained from NMFS/MARAD Ships of Opportunity running out of New York. Two XBT transects in 1974 had sufficiently close station spacing to attempt a verification of the satellite portrayals as follows:

Position From XBT Transect	Position From Satellite Chart
Aug 14, 1974 152 km ± 28 km at 140° from Sandy Hook	Aug 12, 1974 162 km ± 10 km (at 140°)
Oct 10, 1974 214 km ± 17 km at 177° from Sandy Hook	Oct 11, 1974 216 km ± 25 km (at 177°)

The positions of the Shelf Water front were determined from the XBT transects largely on the basis of subsurface horizontal gradients, because the sea surface temperature gradients were weak due to seasonal heating in the upper layer. The close correspondence of frontal positions in the comparisons not only verifies the positions but shows that the front observed by the satellite in these cases was indicative of a mass of water, not just a thin surface layer.

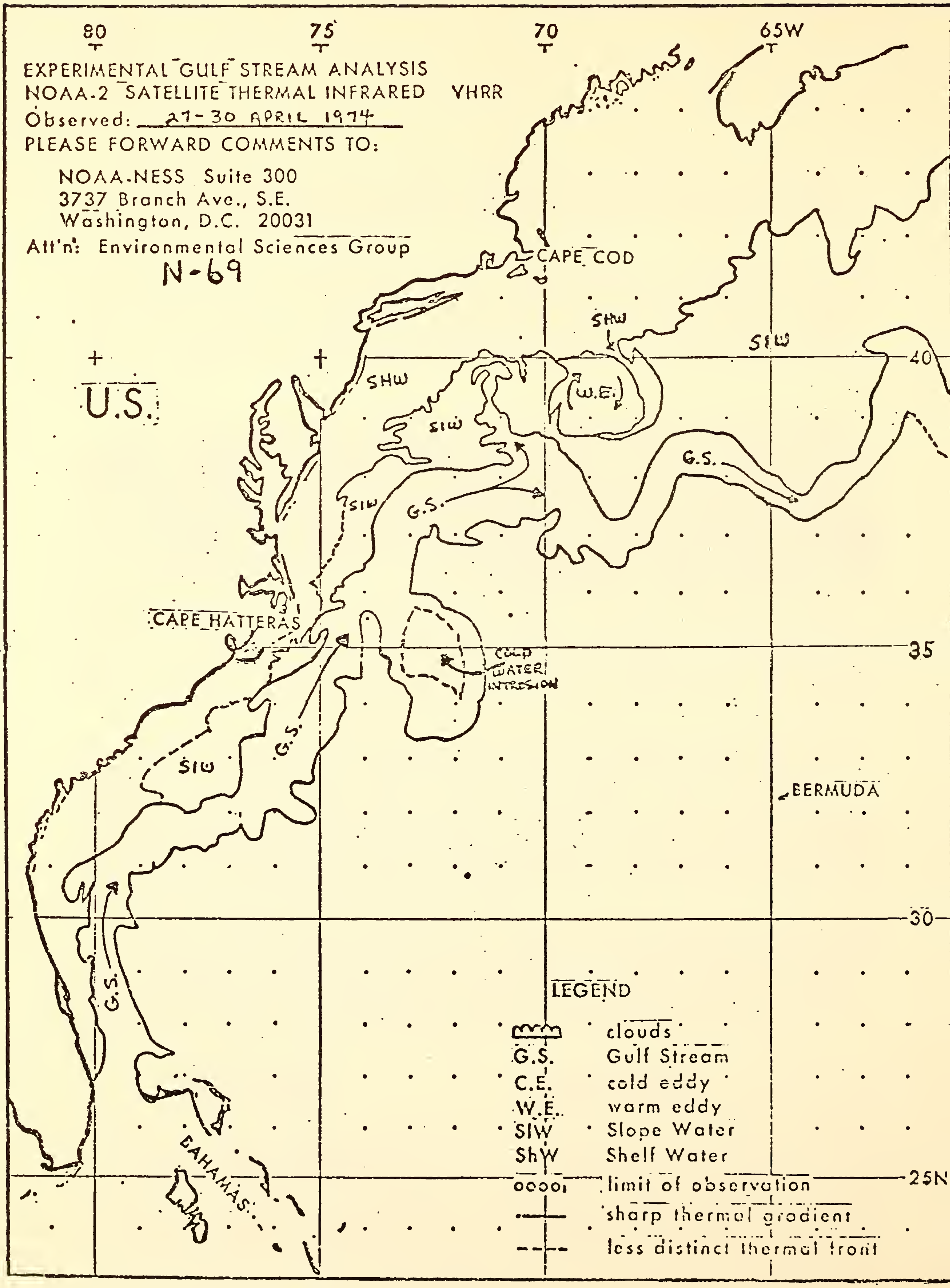

Figure 17-1. Example of weekly frontal analysis chart produced by the National Environmental Satellite Service of NOAA.

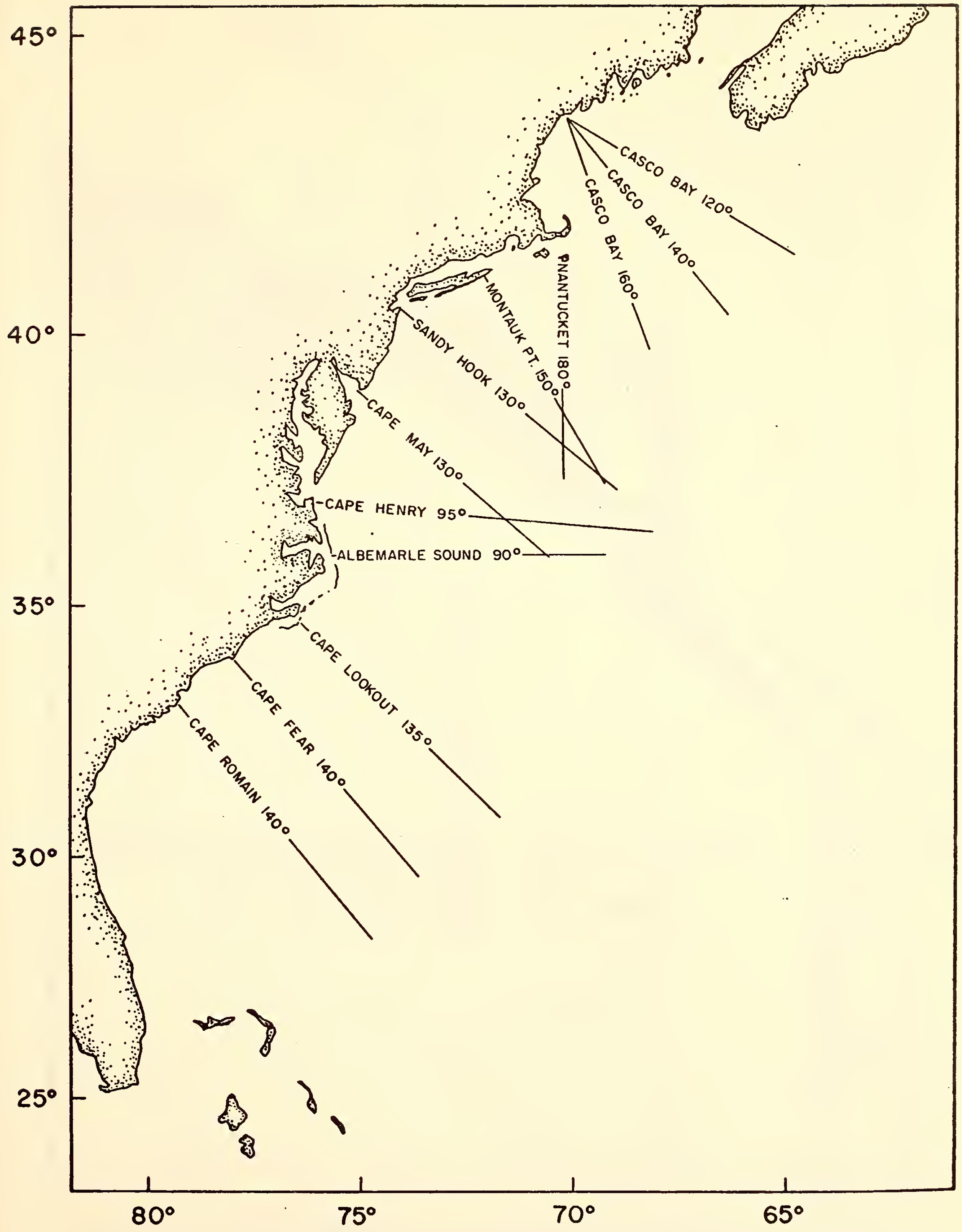

Figure 17-2. Reference points and bearing lines used in the portrayal of the time variation of the Shelf Water front relative to the edge of the continental shelf.

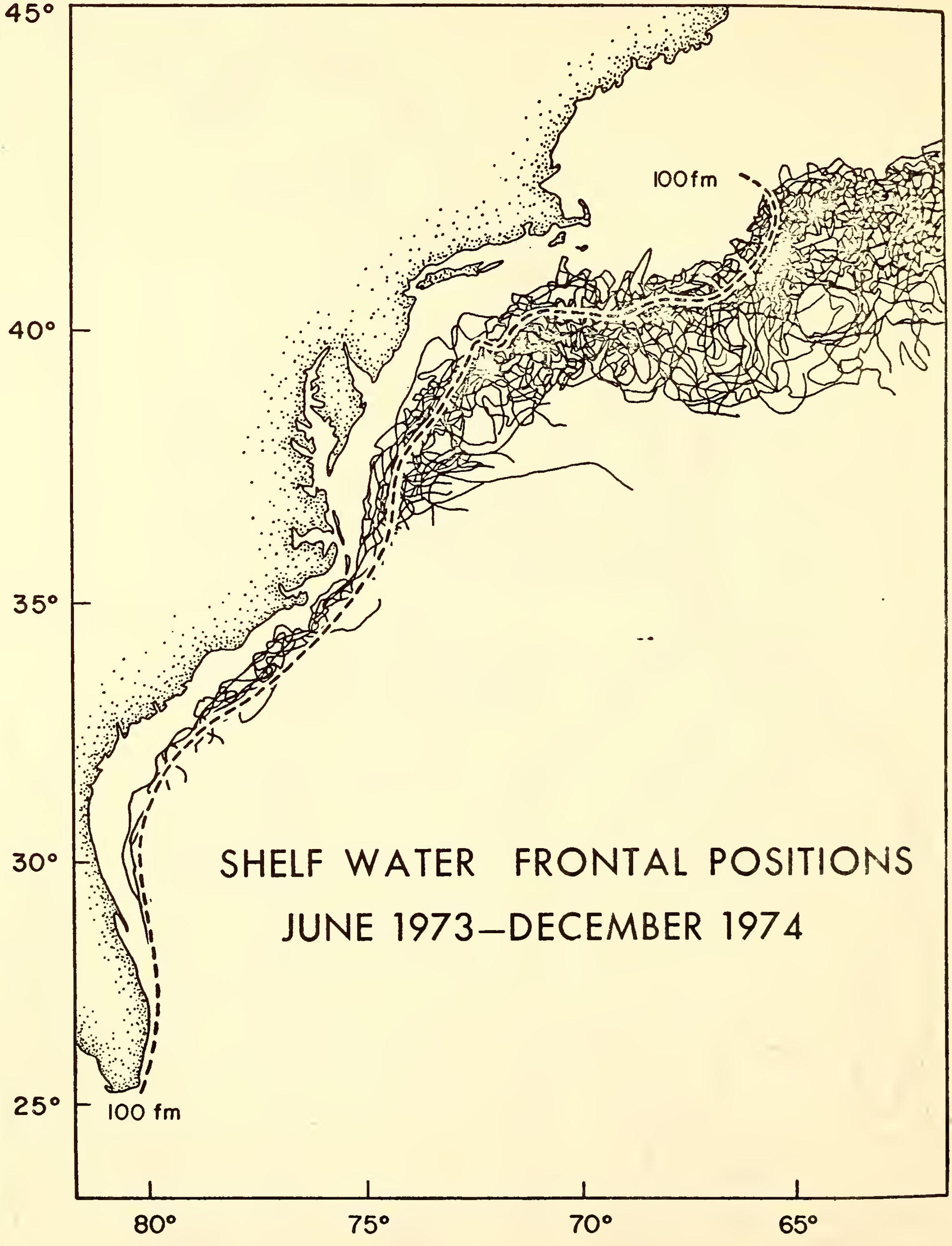

Figure 17-3. Composite plot of positions of the Shelf Water front as observed by Satellite during June 1973 - December 1974. Heavy dashed line indicates location of edge of continental shelf.

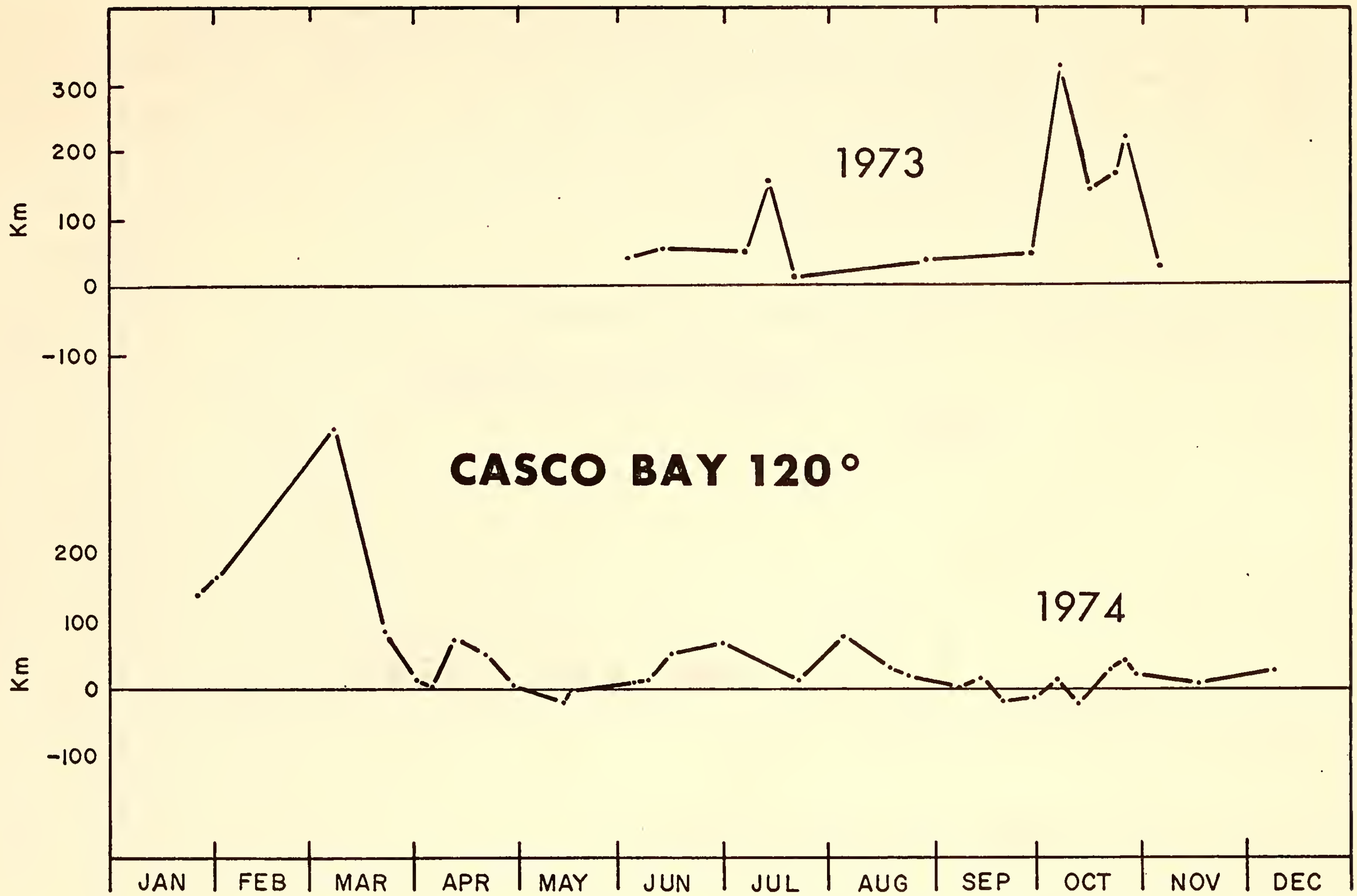

Figure 17-4. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 120° bearing line from Casco Bay, Maine. Positive values are seaward from the shelf edge.

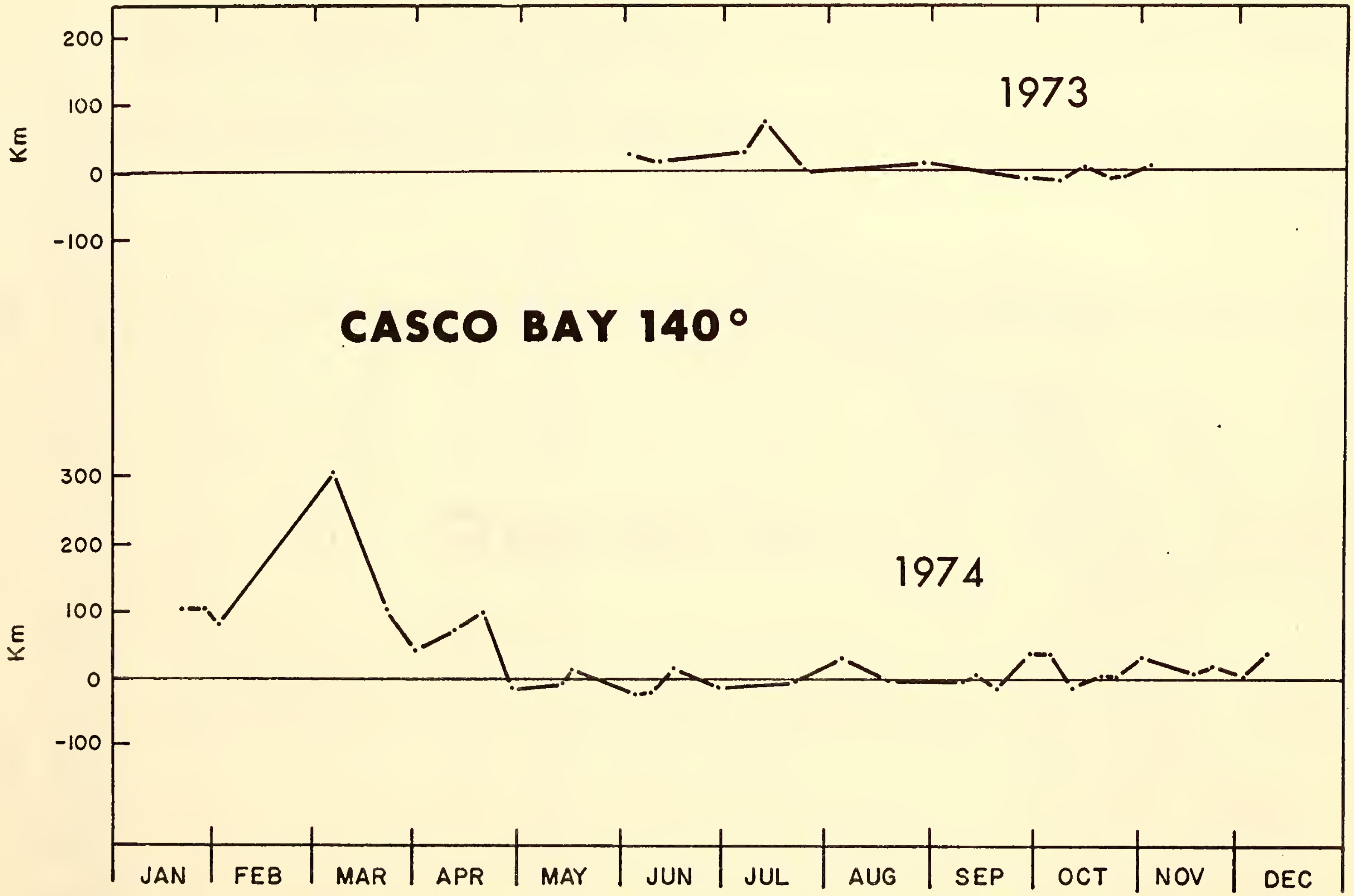

Figure 17-5. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 140° bearing line from Casco Bay, Maine. Positive values are seaward from the shelf edge.

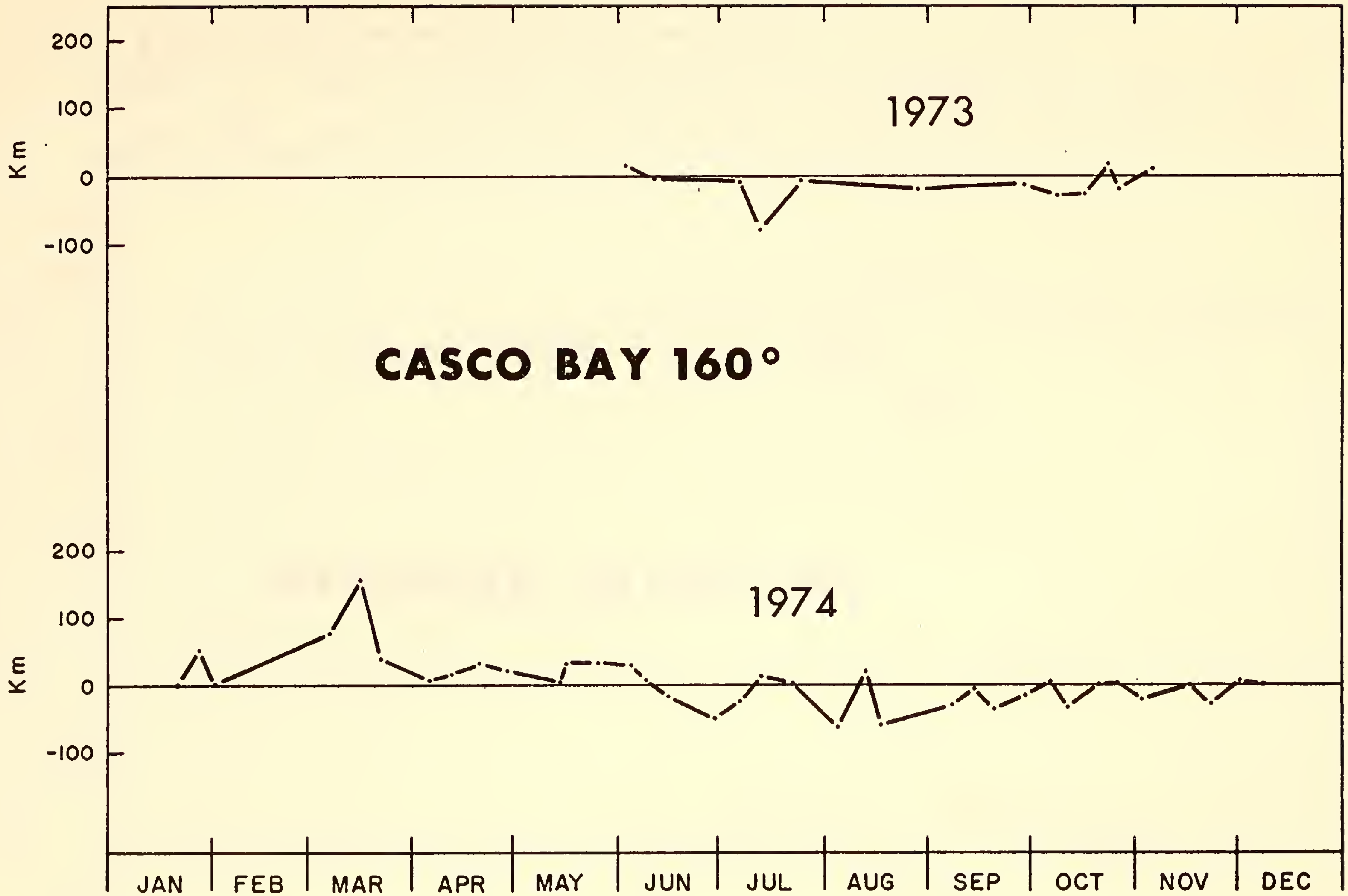

Figure 17-6. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 160° bearing line from Casco Bay, Maine. Positive values are seaward from the shelf edge.

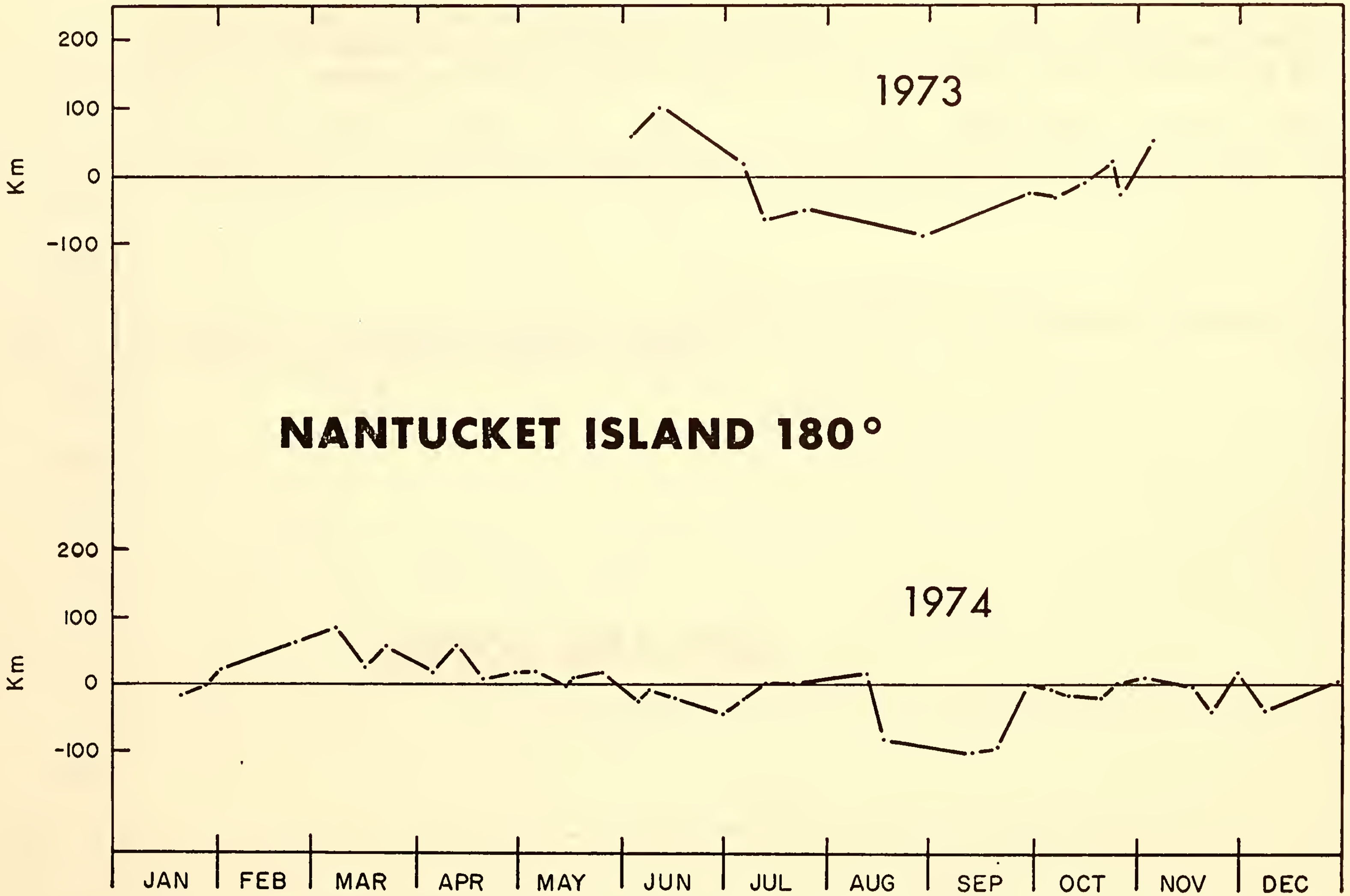

Figure 17-7. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 180° bearing line from Nantucket Island, Massachusetts. Positive values are seaward from the shelf edge.

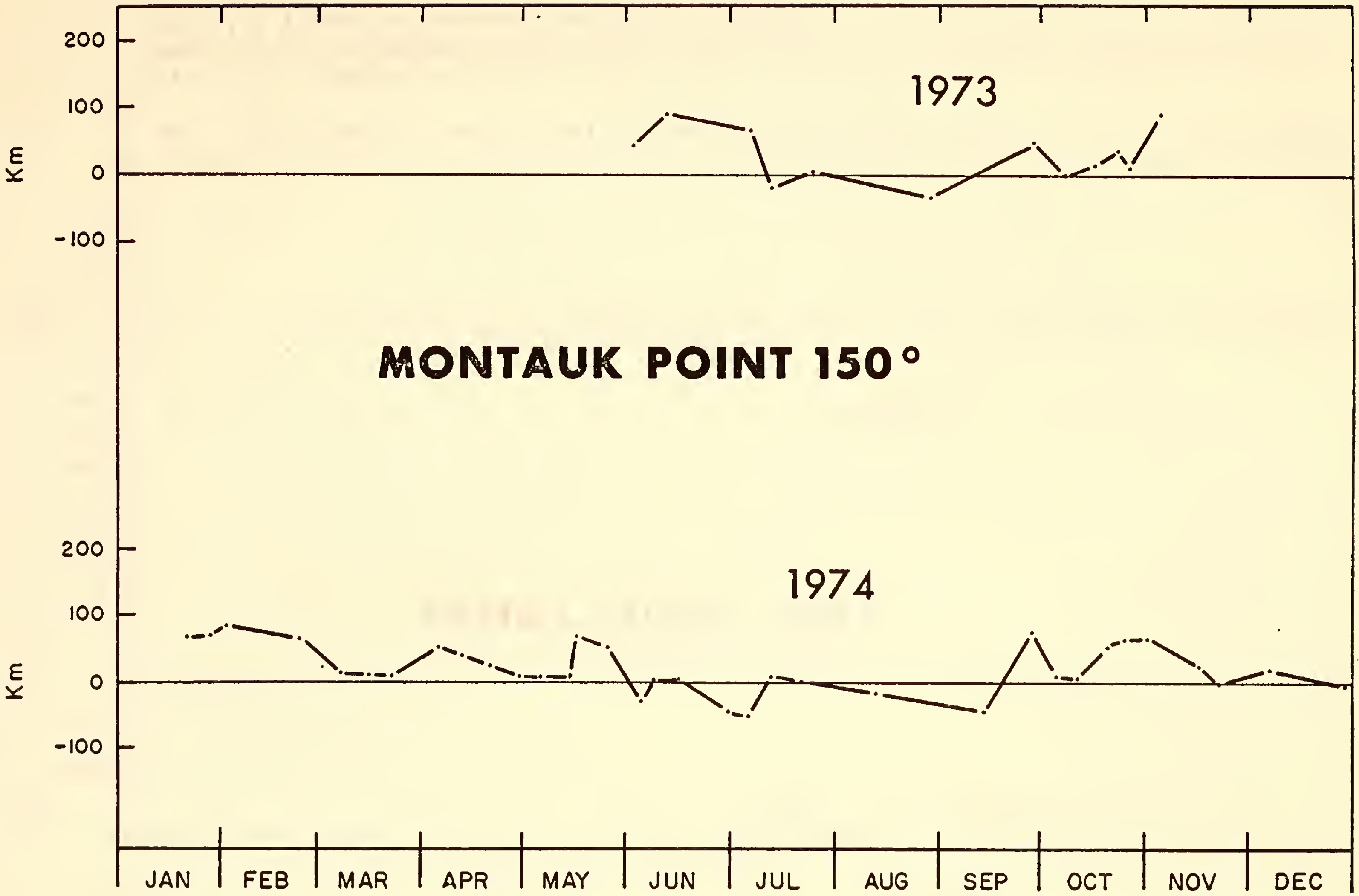

Figure 17-8. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 150° bearing line from Montauk Point, New York. Positive values are seaward from the shelf edge.

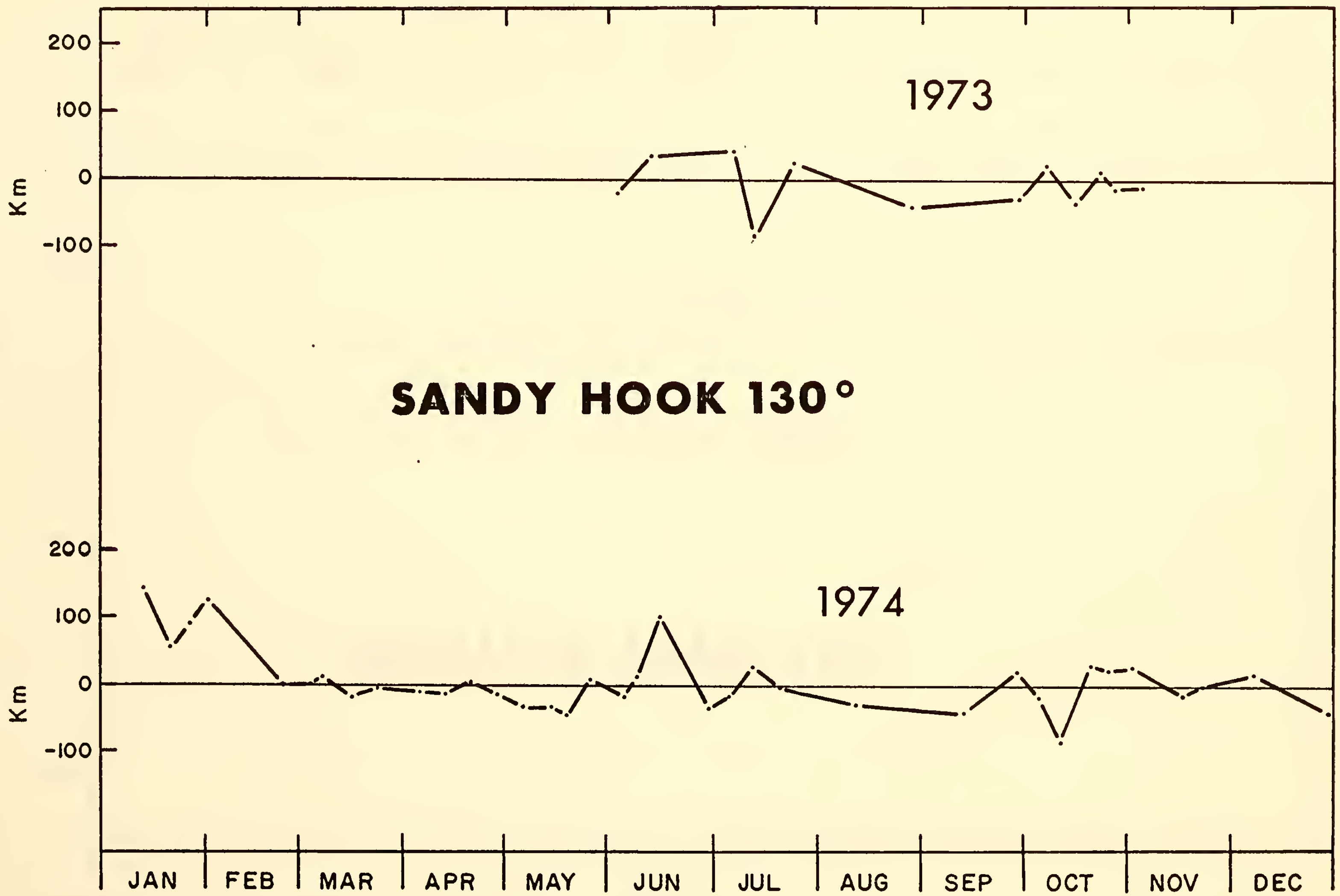

Figure 17-9. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 130° bearing line from Sandy Hook, New Jersey. Positive values are seaward from the shelf edge.

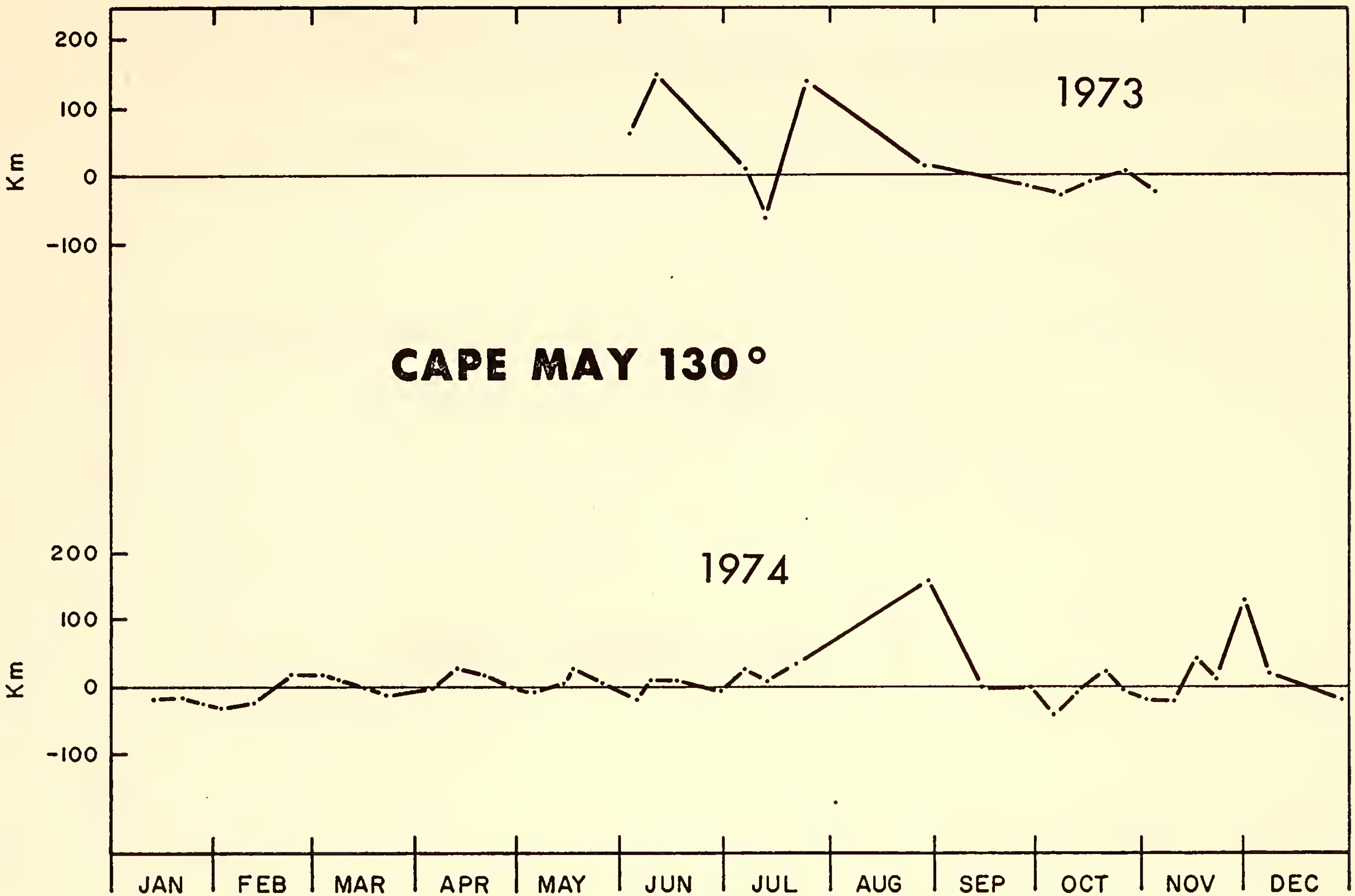

Figure 17-10. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 180° bearing line from Cape May, New Jersey. Positive values are seaward from the shelf edge.

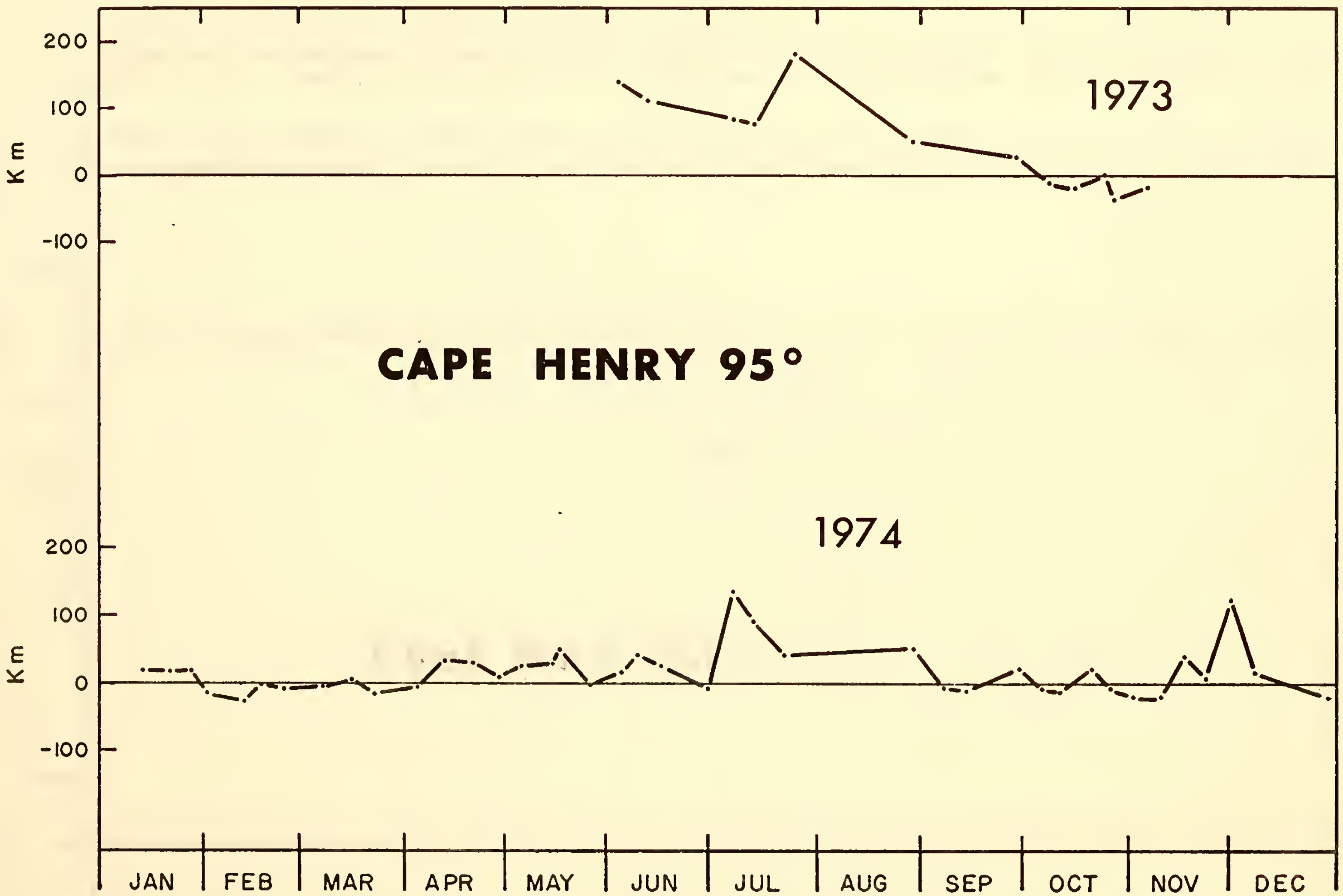

Figure 17-11. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 95° bearing line from Cape Henry, Virgina. Positive values are seaward from the shelf edge.

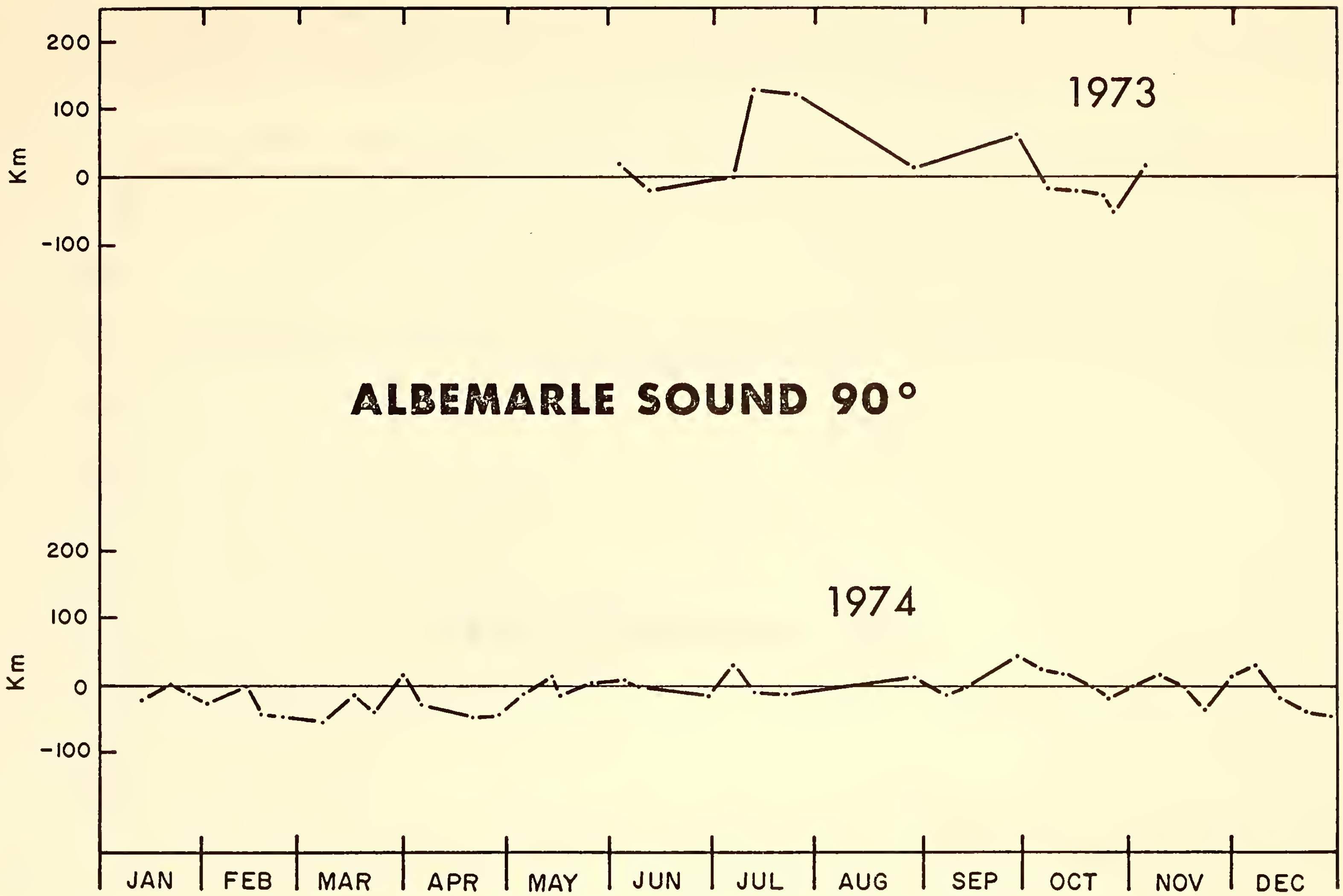

Figure 17-12. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 90° bearing line from Albemarle Sound, North Carolina. Positive values are seaward from the shelf edge.

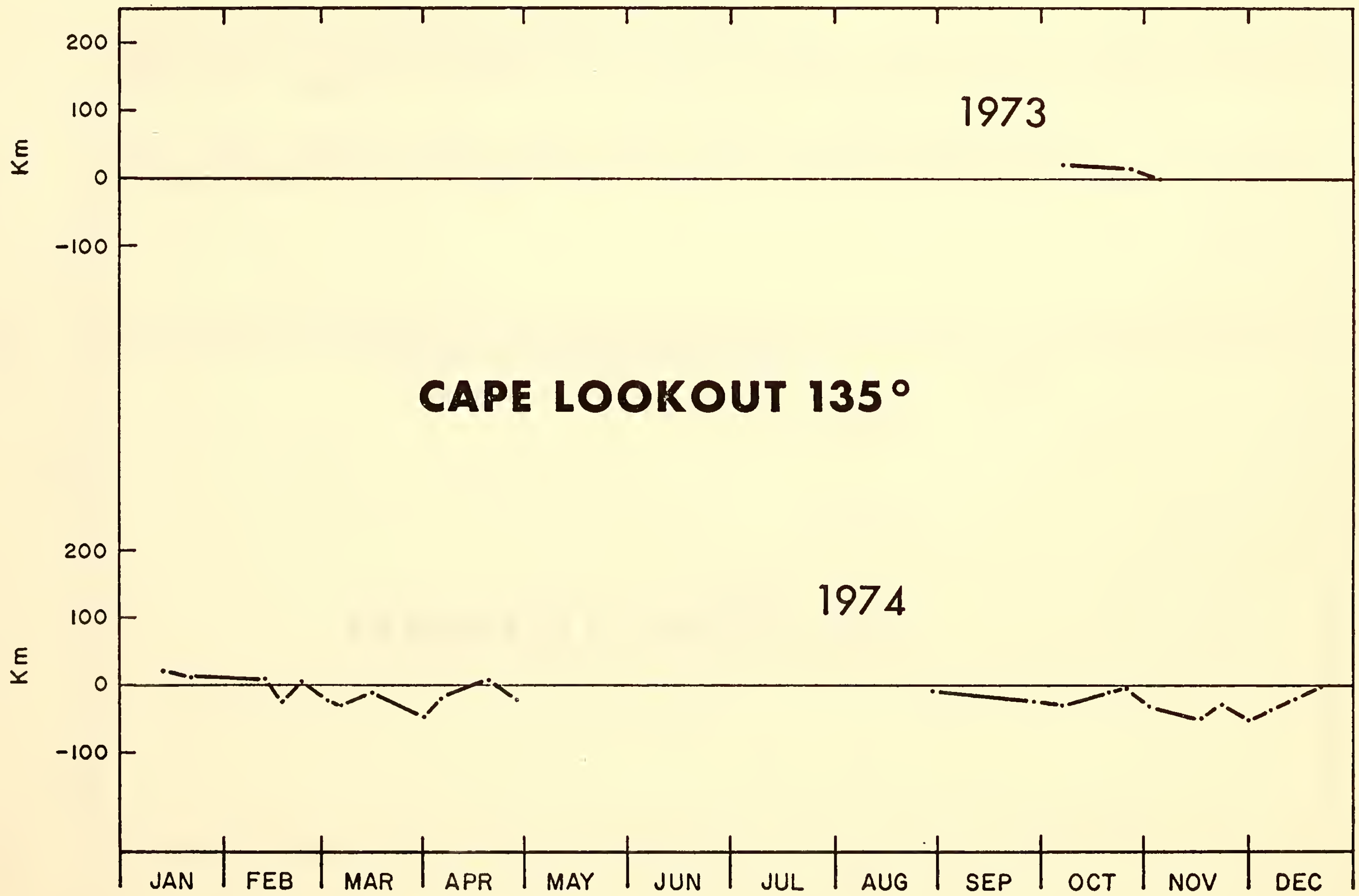

Figure 17-13. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 135° bearing line from Cape Lookout, North Carolina. Positive values are seaward from the shelf edge.

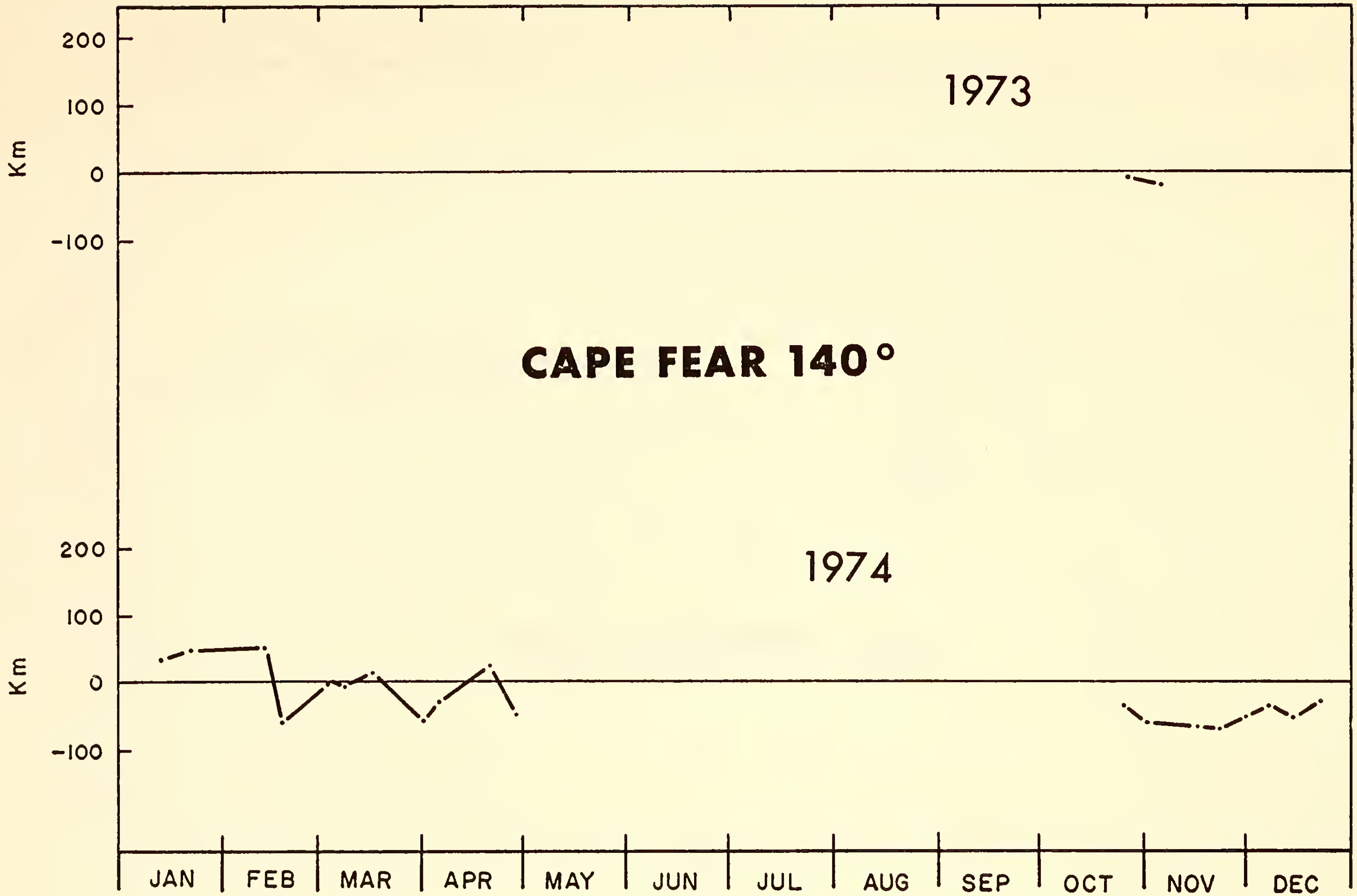

Figure 17-14. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 140° bearing line from Cape Fear, North Carolina. Positive values are seaward from the shelf edge.

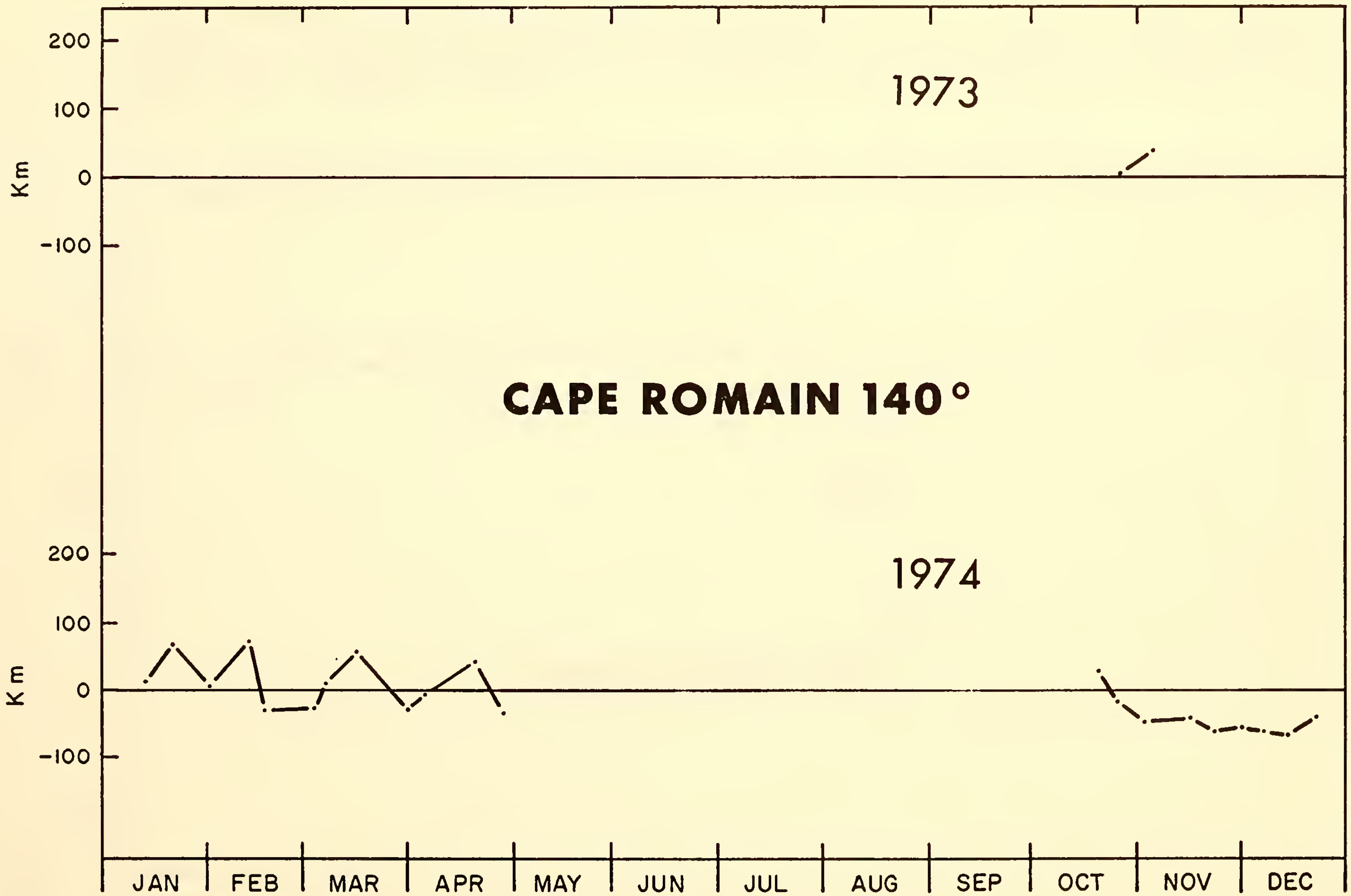

Figure 17-15. Temporal variation of the position of the Shelf Water front relative to the edge of the continental shelf along a 140° bearing line from Cape Romain, South Carolina. Positive values are seaward from the shelf edge.

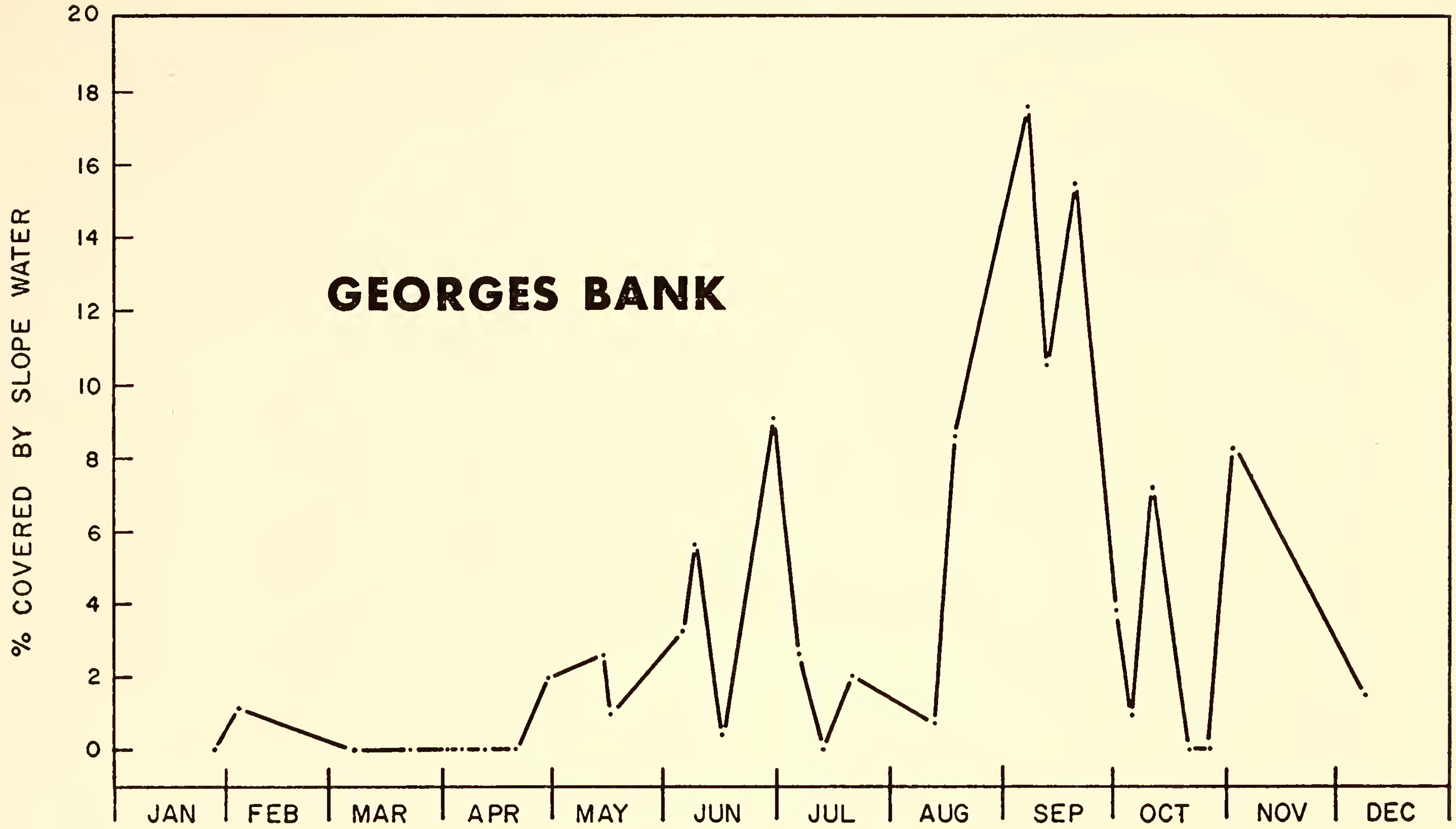

Figure 17-16. Percentage of Georges Bank covered by Slope Water during 1974.

BOTTOM TEMPERATURES ON THE CONTINENTAL SHELF AND SLOPE SOUTH OF NEW ENGLAND DURING 1974

J. Lockwood Chamberlin

Atlantic Environmental Group

Page

BOTTOM TEMPERATURES ON THE
CONTINENTAL SHELF AND SLOPE SOUTH OF
NEW ENGLAND DURING 1974

Preparation of an analysis of bottom temperatures during 1974 for the important fishing grounds of the continental shelf and slope south of New England has been possible because of the large amount of data found available for this region. The data obtained during 20 cruises of 9 different vessels, are mostly from expendable bathythermograph sections made aboard research vessels going to or from Woods Hole. The analysis has entirely depended on the cooperation of several oceanographers, from as many organizations, who generously supplied the data, largely in the form of contoured temperature sections. Their specific contributions are acknowledged at the end of this contribution.

Construction of Bottom Temperature Diagram for 1974 (Figure 1)

A contoured diagram of bottom temperatures (Figure 1) was prepared in three steps:

1. Tabulation of (1) the values of the isotherms on vertical temperature sections and the depths where these intersect the bottom and (2) the actual or extrapolated bottom temperature values that appear on the temperature sections.

2. Plotting the tabulated values at the depths of bottom and at the times of year when the observations were made.

3. Contouring at 1°C intervals. Information from NOAA Satellite imagery on the passage of a warm core Gulf Stream eddy (or ring) through or near the area of the diagram was used as a guide in some of the contour timing. Bottom temperature data from immediately outside the area provided similar guidance on a few occasions. The process of the contouring, itself, led to minor re-interpretations of some vertical sections, concomitant changes in the depths at which bottom temperature values were plotted, as well as the addition of a few values.

Although the diagram is designed to show only the gross pattern of bottom temperature change in the region south of New England, it has, because of the manner of its construction, a characteristic that could be misleading, unless explained. The temperature sections used for the diagram all run in a more or less north south direction across the shelf and slope, but are from various positions between 69°47' and 71°18'W longitude (a band about 70 nautical miles wide) (Figures 3-4). In the diagram, however, they are treated essentially as though all were from a single line or narrow band. An adverse result of this treatment is possible ambiguity in the timing of the "temperature events" as displayed, because the apparent timing, although largely a product of the actual timing of temperature changes, is partly a product of the relative spacial locations of the successive sections. Because the shelf and slope region south of New England extends generally east-west and the main direction of the circulation is westward (Bumpus, 1973), sections from the eastern part of the region tend to give an "early" bias to the timing and sections in the west a "late" bias. As an aid to making judgments regarding these biases, the geographical positions of the sections used are shown in Figures 3 and 4. The flow rates in the area (Bumpus, 1973) indicate that most of the timing errors from this bias will not exceed a week or two.

General coherence of the diagram supports the assumption that the temperature regime in the region covered is reasonably homogenous. This assumption is also supported by previous studies of this region, such as those of Bigelow, 1933, Walford and Wicklund, 1968, and Colton and Stoddard, 1973.

Construction of long term monthly mean bottom temperature diagram--1940-66 (Figure 2)

To provide a basis for comparison with the diagram of bottom temperatures during 1974, a similar one was constructed based on mean monthly bottom temperatures (Figure 2). The data employed were selected from mean monthly values computed by Colton and Stoddard (1973) for preparation of an atlas of bottom temperatures on the continental shelf from Nova Scotia to New Jersey (Colton and Stoddard 1973). These mean values were computed for the period 1940-66, from data extracted from the bathythermograph file in the Woods Hole Oceanographic Institution. The particular mean values used in preparing Figure 2 are those for the quarter degree squares between 70°30' and 71°00'W longitude.

Bottom Temperatures in 1974

Incursion of Warm Core Gulf Stream Eddy in March:- By far the most striking feature in the bottom temperature diagram is the sequence of strong and abrupt warming and cooling during March over most of the width of the continental shelf and downward on the continental slope to below 360 meters. This temperature anomaly, occurring at the time of year when the bottom temperatures have usually been at their annual minimum (Figure 2), was caused by a warm core Gulf Stream eddy which entered the region from the east and moved unusually close along the continental slope (Applications Research Division, U.S. Naval Oceanographic Office, 1974).

The pronounced effect of this eddy on bottom temperatures is clearly shown by an expendable bathythermograph section taken on March 28-29 by NMFS scientists of the Northeast Fisheries Center aboard the RV "Albatross" in the course of the annual spring groundfish survey (Figure 5). Temperature sections from three other vessels that operated in the region during March and early April also show the presence of the eddy, but indicate marked fluctuations in its effect on bottom temperatures. Fortunately, five of these sections (one from the R/V "Albatross IV", one from the USCGC "Dallas", and 3 from the R/V "Verrill") were made along nearly the same track line, particularly at the offshore end (Figure 4). Data from these sections were, therefore selected when preparing the bottom temperature diagram (Figure 1) for the period March 1 - April 5, so as to present the best available evidence on the rates of change of bottom temperatures.

To obtain additional information on the progress of the eddy through the southern New England region, its positions at the surface, as revealed by NOAA satellite imagery, were compiled for the months of January to June (Figure 6). This compilation is based on:

1) the Experimental Gulf Stream Analysis, issued weekly by the National Environmental Satellite Service,

2) the Experimental Ocean Frontal Analysis, issued semi-monthly by the U.S. Naval Oceanographic Office,

3) interpretive tracings from the satellite imagery of the positions of eddies and fronts (on file at the U.S. Naval Oceanographic Office), and

4) personal re-interpretation of the satellite imagery for the first half of April

The resulting "track line" of the eddy (Figure 6) shows:

1) relatively steady westward movement at an average speed of about 0.2 knots (10 cm/sec) from south of Georges Bank into the southern New England region, during the period from late January until early March

2) irregular movement in the region south of New England, from early March until mid May, and

3) relatively steady southwestward movement at an average speed of about 0.17 knots (8 cm/sec) from south of New England to the latitude of Virginia, during the period from mid May to the end of June, after which time the eddy was no longer observed in the satellite imagery.

Although stagnation of the eddy in the southern New England region from March until mid May is clearly demonstrated in Figure 6, the details of movement as diagrammed should not be regarded as very accurate, because:

1) Mismatch problems encountered when overlaying the available transparent graticules on the satellite imagery prints indicates a positional recovery error of about 10 to 20 nautical miles, and

2) the apparent center of the eddy at the surface as seen in the satellite imagery, may often be many miles from the core of the eddy below the surface, because of surface over-riding by entrained or wind driven shelf and slope water

The stagnation of the eddy south of New England, from early March until mid May (Figure 6), indicates that its effect on bottom temperatures in this region may have been more prolonged than appears in Figure 1. Irregular movement of the eddy throughout this period suggests that repetitive contacts with the bottom, such as apparently occurred during March (Figure 1) may also have occurred during April and early May. This possibility is left open to question by the few vertical temperature sections found available for the months of April and May. To the westward of the southern New England region, however, in the vicinity of the Hudson Canyon, temperature sections show that the eddy made strong contact with the continental slope on May 19-20, apparently causing bottom temperature elevations above 14°C to a depth of about 300 meters (Gulf Stream Monthly Summary, June and December, 1974).

A special note was published by the Applications Research Division (1974) on the unusual character of this eddy. It remained close to the continental shelf throughout its observed life and had a core temperature at 200 meters of only 14.4°C. They observed that in contrast "an anticyclonic eddy formed in late August 1970 contained much 18° water when surveyed on 13 December 1970", and suggested that the

1974 eddy, having formed in mid winter, lost more heat to the atmosphere than the eddy of 1970.

Interpretations of satellite imagery reveal the passage of only one other warm core eddy through the region south of New England during 1974 (personal communication, J.J. Bisagni, Atlantic Environmental Group, NMFS). This eddy, however, was apparently too far to the south during the passage--in late June and early July--to have had a warming effect on the continental shelf and slope. Although no vertical temperature sections have been found to document the bottom temperature effect of this eddy in the southern New England region during the time of its passage, sections from farther to the west -- in the Hudson Canyon area-- show the eddy to have been far off the continental slope in mid July (Gulf Stream Monthly Summary, December 1974).

Bottom Temperatures Above Normal Throughout the Year:- Comparison of Figures 1 and 2 shows that bottom temperatures on the outer continental shelf and upper continental slope were generally a few to several degrees centigrade warmer during 1974 than the monthly mean temperatures for the years 1940-66. In the warm band on the outer shelf, where Slope Water usually is in contact with the bottom, maximum temperatures were not recorded lower than 12°C in 1974. In the mean temperature diagram, however, the maximum values in this warm band are below 11°C from mid-February through April and below 9°C in March (Figure 2). At mid depth on the continental shelf in 1974, the characteristic core of cold bottom water (Bigelow, 1933) was about 2°C warmer than the monthly mean values, from the time of its formation in February until the autumn when it was dissipated by vertical mixing of the water column.

In the Hudson Canyon area, just to the west of southern New England, bottom temperatures on the outer continental shelf during 1974 can be compared with those of the immediately preceding years. Vertical temperature sections obtained by the Naval Oceanographic Office on passenger liners between New York and Bermuda from spring to fall in 1970, -71, -73, and -74 indicate that the bottom temperatures during the months of observations in 1974 (March-October) were similar to those south of New England, but generally 1° to 2°C warmer than in any of the previous years (Gulf Stream Monthly Summary, November 1970, December 1971, July 1974, and December 1974).

Acknowledgments

Compilation of the data used here was stimulated by the suggestion of John B. Colton, Jr., National Marine Fisheries Service, Northeast Fisheries Center, that temperature sections had been collected year around in southern New England waters by scientists at the Woods Hole Oceanographic Institution since 1969. He also provided the data used in preparing the

diagram of monthly mean bottom temperatures (Figure 2). A majority of the temperature sections used in the present analysis were provided by W. Redwood Wright, WHOI, who had assembled them in conjunction with his research on the slope water front. He had collected some of them himself, at sea, and obtained the rest through the cooperation of other scientists. The sections from this source are those indicated in Figure 1 from vessels "Knorr", "Chain", "Eastward", and "Westward". Sections from the Coast Guard Cutter "Dallas" and R/V "Verrill" were obtained from a data report (Flagg and Beardsley 1975). Charles N. Flagg, Massachusetts Institute of Technology, kindly supplied additional data relating to these sections. In addition, Charles W. Morgan, U.S. Coast Guard Oceanographic Unit, sent sections he had prepared from 2 cruises of the Cutter "Evergreen". The data for the sections from the"Albatross IV" were provided by Samuel R. Nickerson, Northeast Fisheries Center, National Marine Fisheries Service. Two sections from the passenger liner "Sea Venture" were used as published in the Gulf Stream Monthly Summary, December 1974. Alvan Fisher, Jr. and G.J. Potocsky, Applications Research Division, U.S. Naval Oceanographic Office, supplied copies of the Experimental Ocean Frontal Analysis, made available files of NOAA satellite imagery, and provided valuable advice. In the Atlantic Environmental Group, NMFS, John J. Kosmark carried out much of the data processing for the figures and Reed S. Armstrong gave helpful advice.

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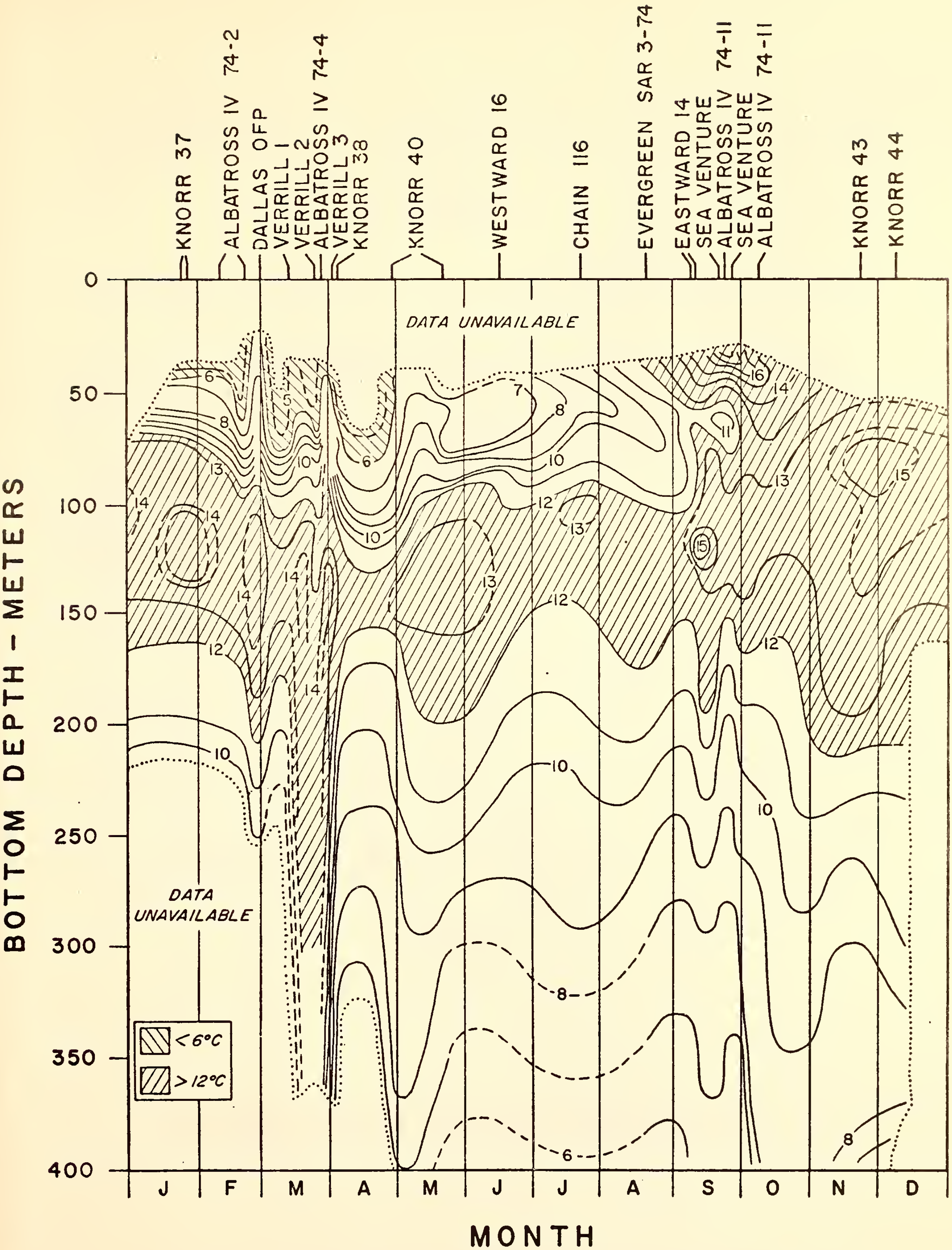

Figure 18.1 Bottom temperatures on the continental shelf and slope south of New England during 1974. The vessel cruises shown at the top of the figure are the sources of the vertical temperature sections used in constructing the diagram.

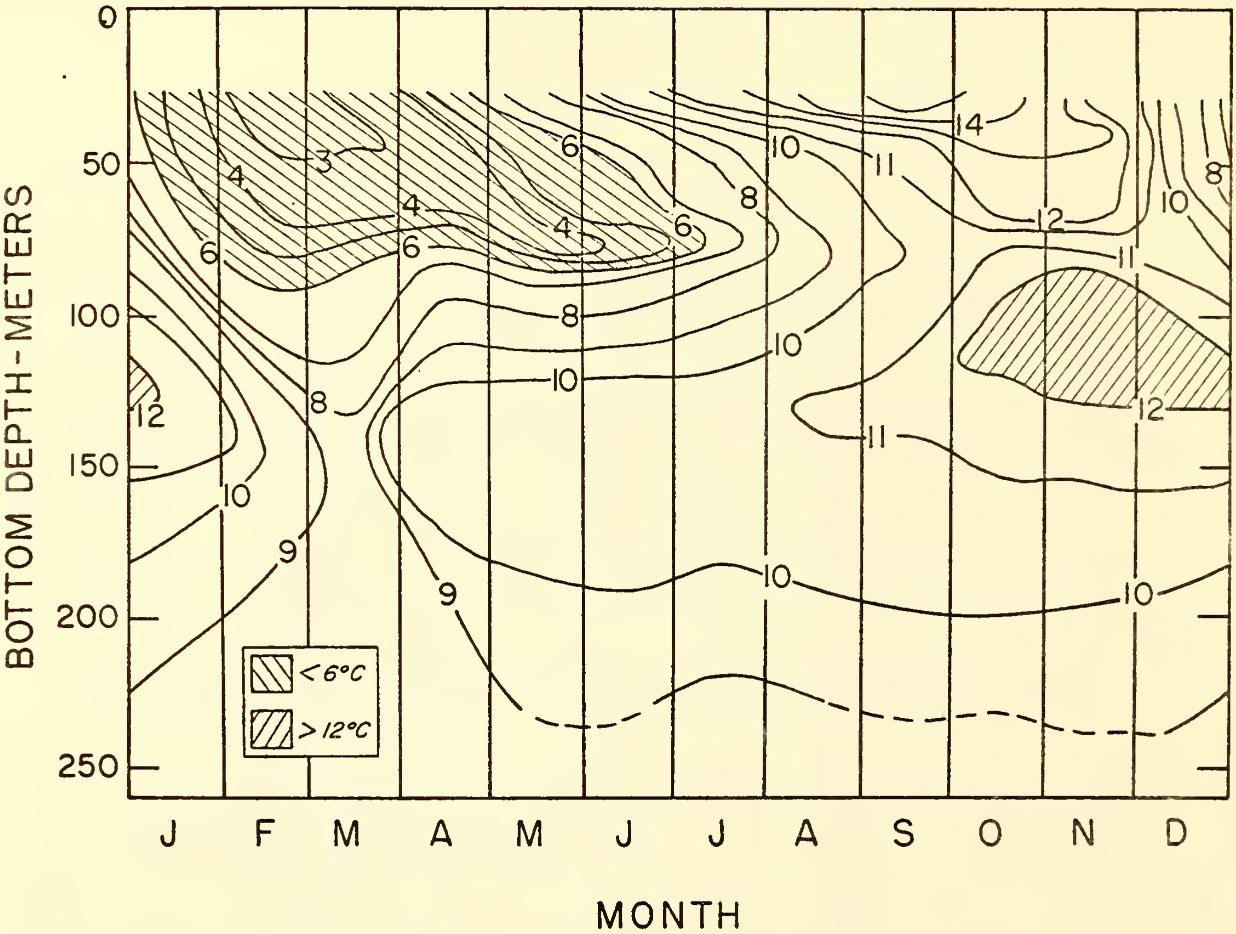

Figure 18.2 Mean monthly bottom temperatures on the continental shelf and slope south of New England for the years 1940 - 66.

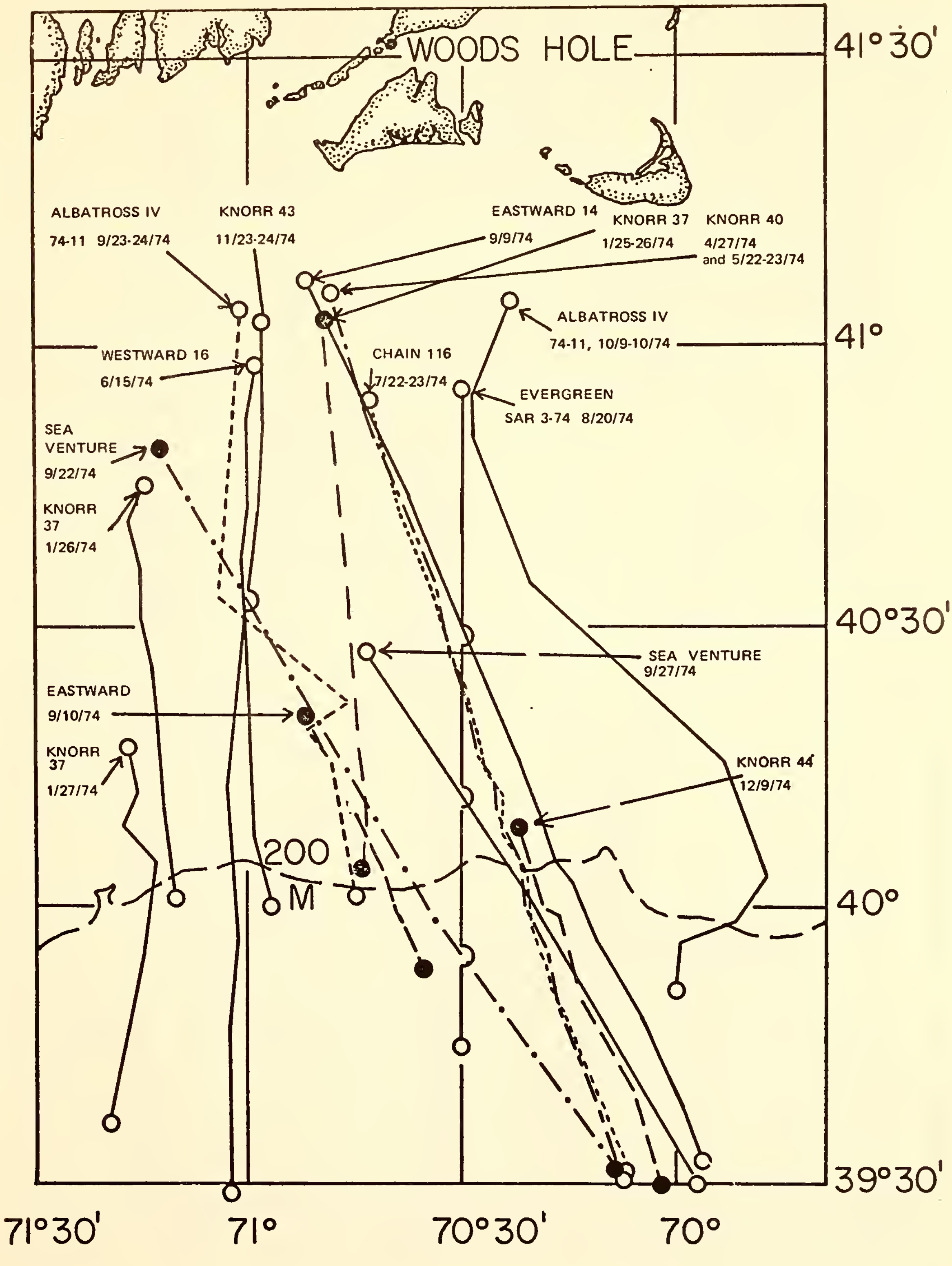

Figure 18.3 Locations of vertical temperature sections used in constructing Figure 1, except for those from the period March 1 to April 5 (see Figure 4).

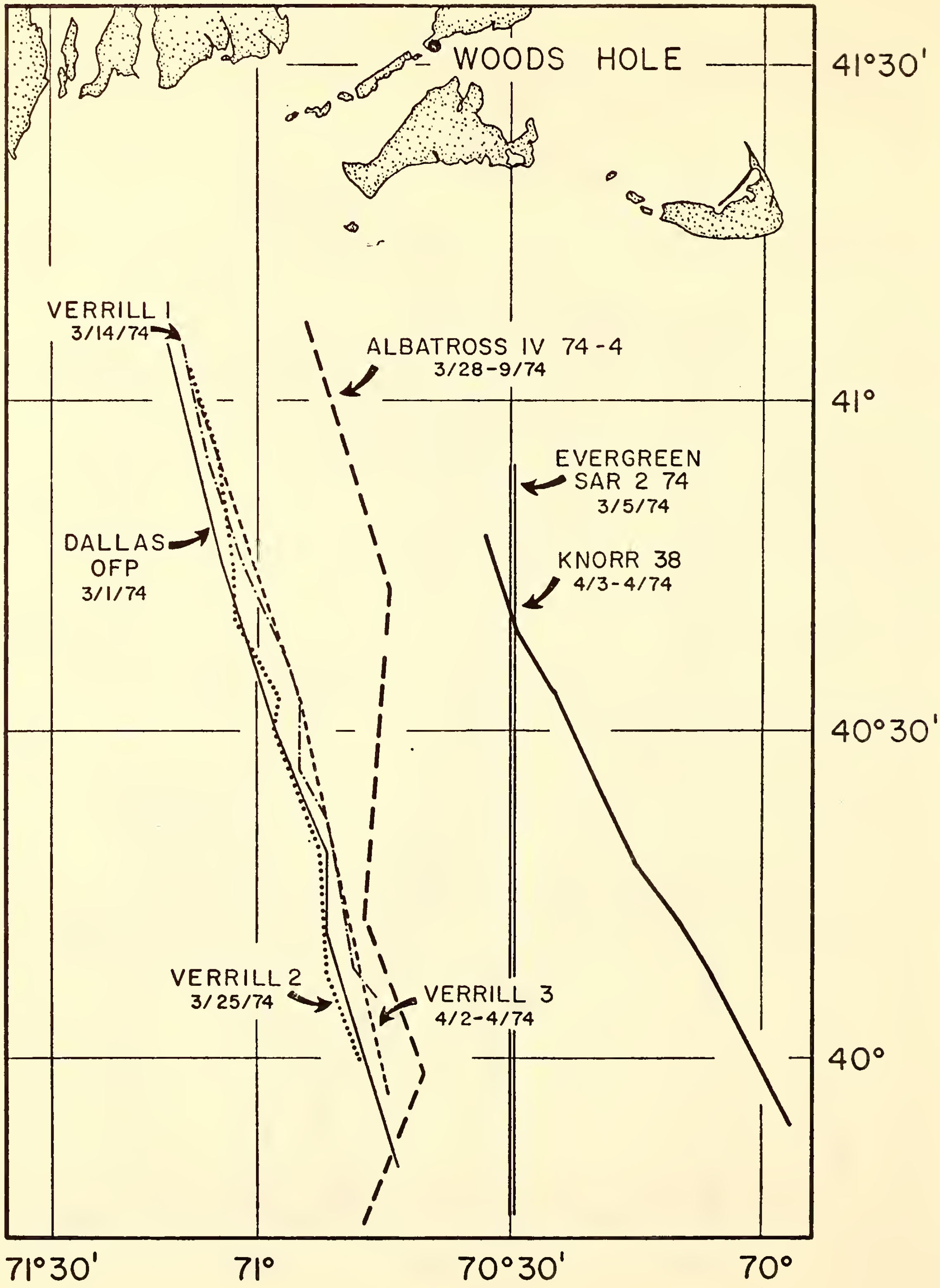

Figure 18.4 Locations of vertical temperature sections used in constructing Figure 1, for the period March 1 to April 5 (see Figure 3 for locations of the sections used for the rest of the year).

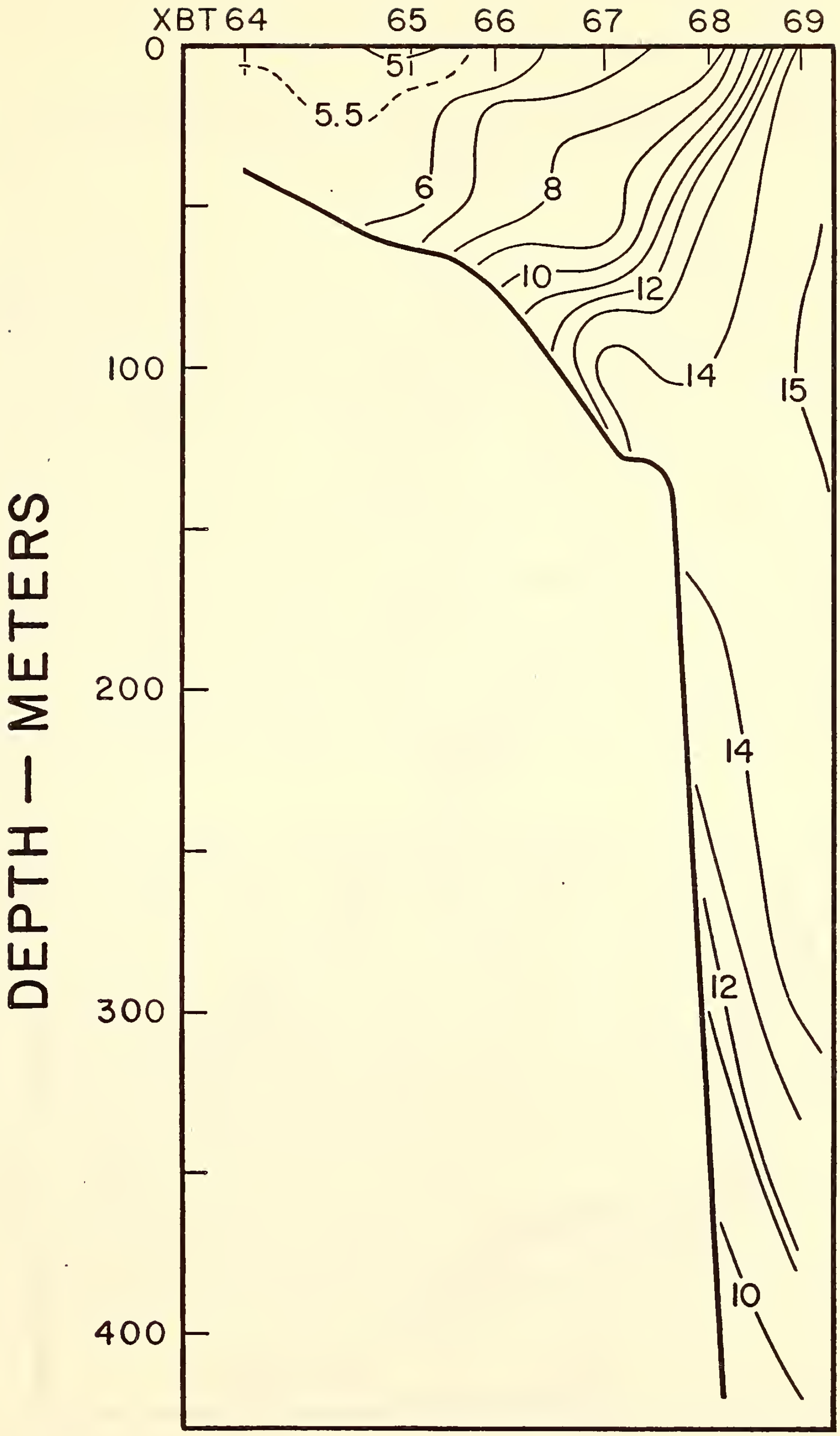

Figure 18.5 Temperature section, from "Albatross IV" Cruise 74-4, running southward from Martha's Vineyard on March 28-29, 1974.

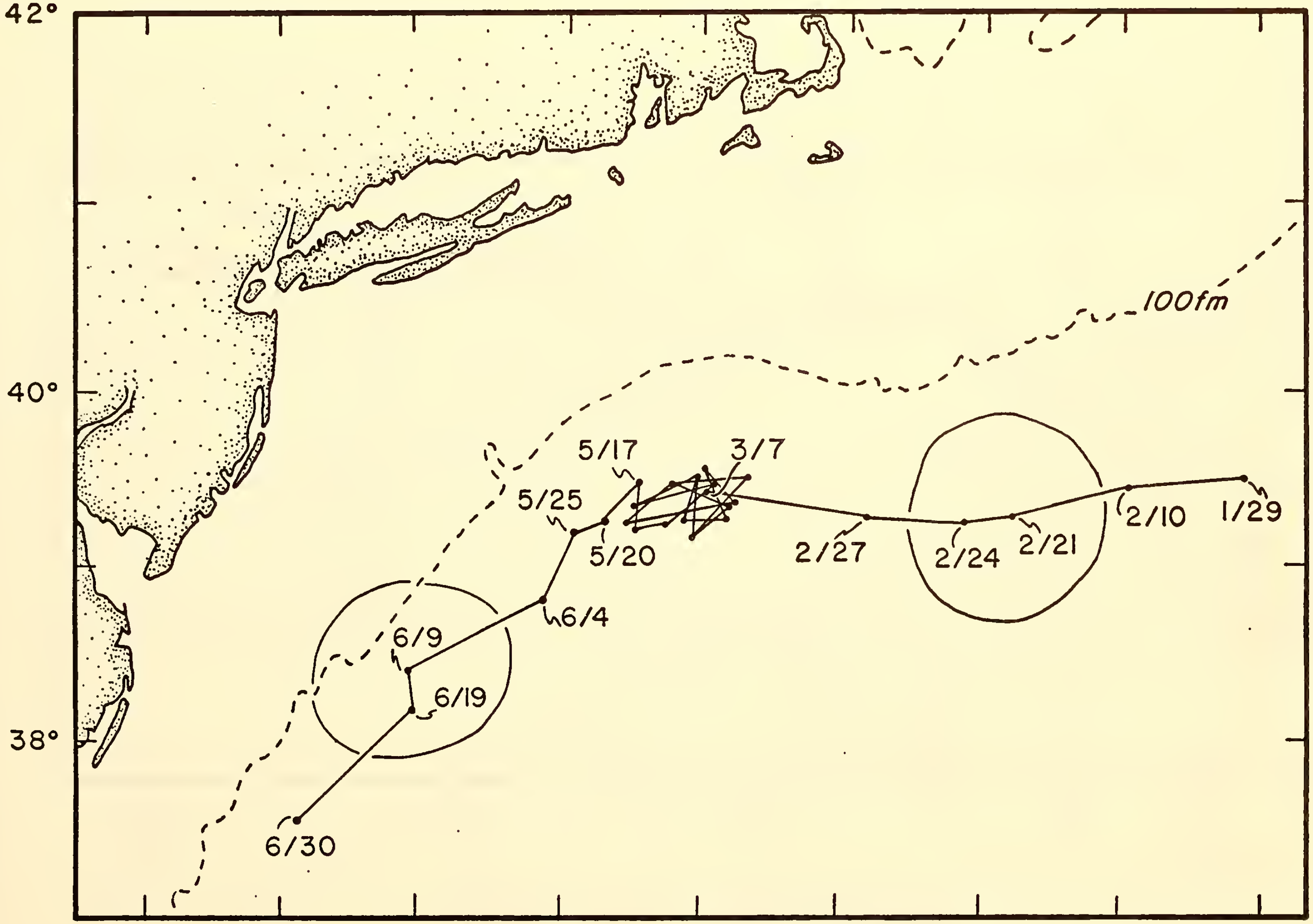

Figure 18.6 Movement of warm core Gulf Stream eddy from south of Georges Bank to the latitude of Virginia from late January to the end of June, as interpreted from satellite imagery. Each eddy position shown is the approximated center of the surface signature on the date indicated. Simplified outlines of the surface signature are shown for February 21 and June 9.

TIDAL STATION TEMPERATURES

U.S. EAST COAST AND LONG ISLAND SOUND

J. R. Goulet, Jr.
Atlantic Environmental Group

Mean monthly temperatures from observations at tidal stations along the U.S. east coast and Long Island Sound were contoured on a distance versus time plot for 1973 and 1974. The change in temperature between months, to indicate warming and cooling, was also contoured. The east coast data (figs. 1 & 2), from Montauk to Key west, were plotted versus latitude, while the Long Island Sound data (figs. 3 & 4), from New Rochelle to Buzzards Bay, were plotted versus longitude.

In Long Island Sound, the temperatures showed the onset of warming in late January both in 1973 and 1974. The peak of warming occurred in late April in 1973 and reached slightly higher values than in 1974 when it occurred in early April. The onset of cooling occurred in late July in 1973 and early August in 1974. Cooling was not as intense in 1974 but the peak of cooling began one month earlier and persisted longer. Maximum temperatures at Bridgeport reached above 75°F in August 1973, but did not reach as high in 1974. In December 1973 the temperatures the length of Long Island Sound did not fall below 45°F, but did so in 1974.

In the Mid-Atlantic Bight, from Montauk to Cape Hatteras, the temperatures at tidal stations showed no noticeable differences between 1973 and 1974, except just north of Cape Hatteras where they were up to 5°F warmer in January-February 1974. The warming and cooling cycle also shows very little difference between 1973 and 1974. The peak of warming is a little more intense in 1974, but begins slightly later and ends slightly earlier. The peak in cooling extends from September through December in 1973. In 1974 the cooling peak starts earlier, weakens in November, and peaks again in December. Warming begins in late January both in 1973 and 1974 except just north of Cape Hatteras where it begins in early January in 1974.

Along the southeast U.S. coast, temperatures at tidal stations show that 1974 was slightly warmer than 1973. Warming began in early January in 1974, but only in February in 1973. Cooling began in July 1973 and August 1974. Cooling in October-December was more intense in 1974 than 1973, so that the two years ended with nearly equal temperatures.

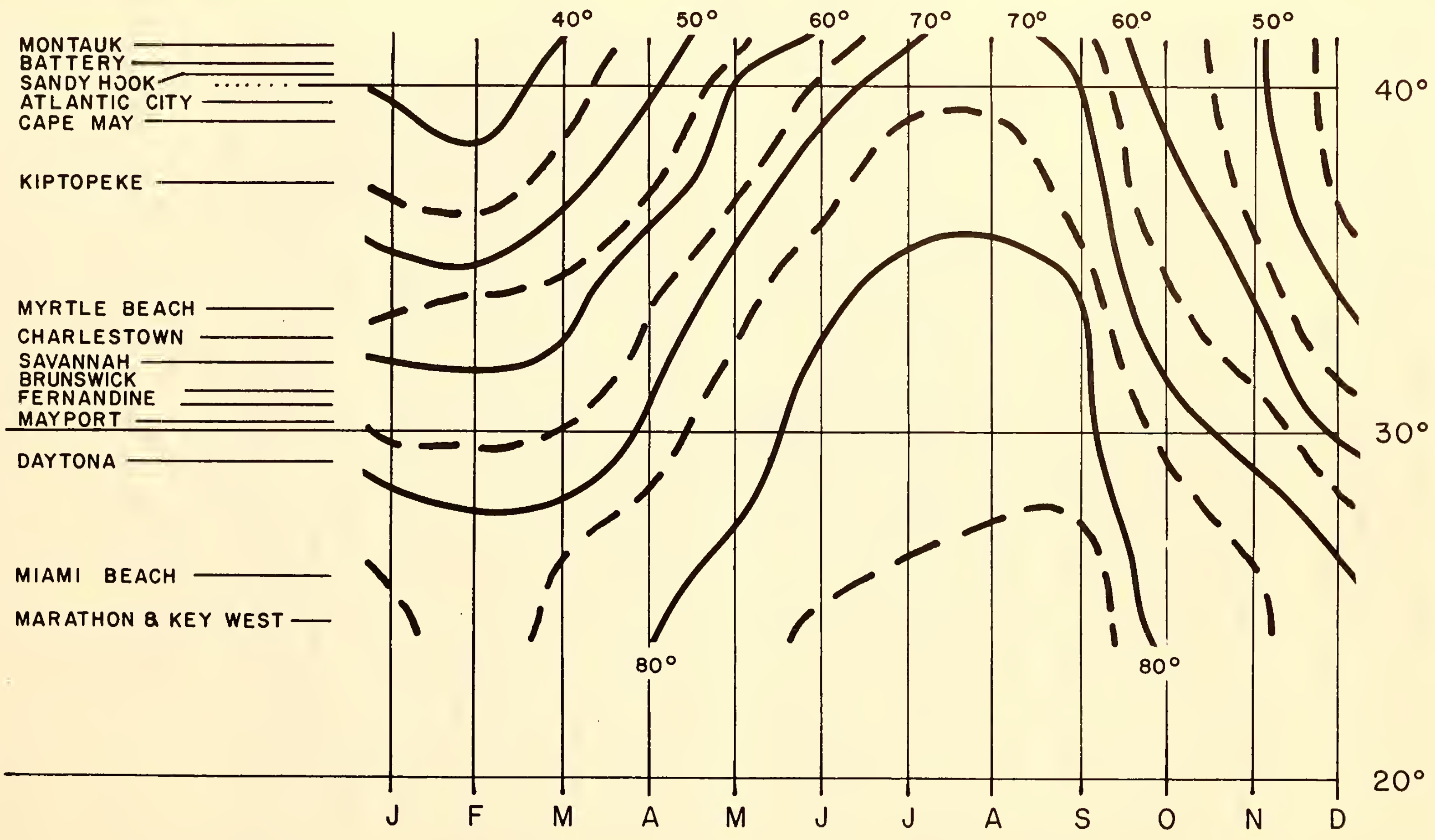

Figure 19.1a Mean monthly 1974 temperatures at east coast tide stations, Montauk to Key West. Contour interval is 5°F.

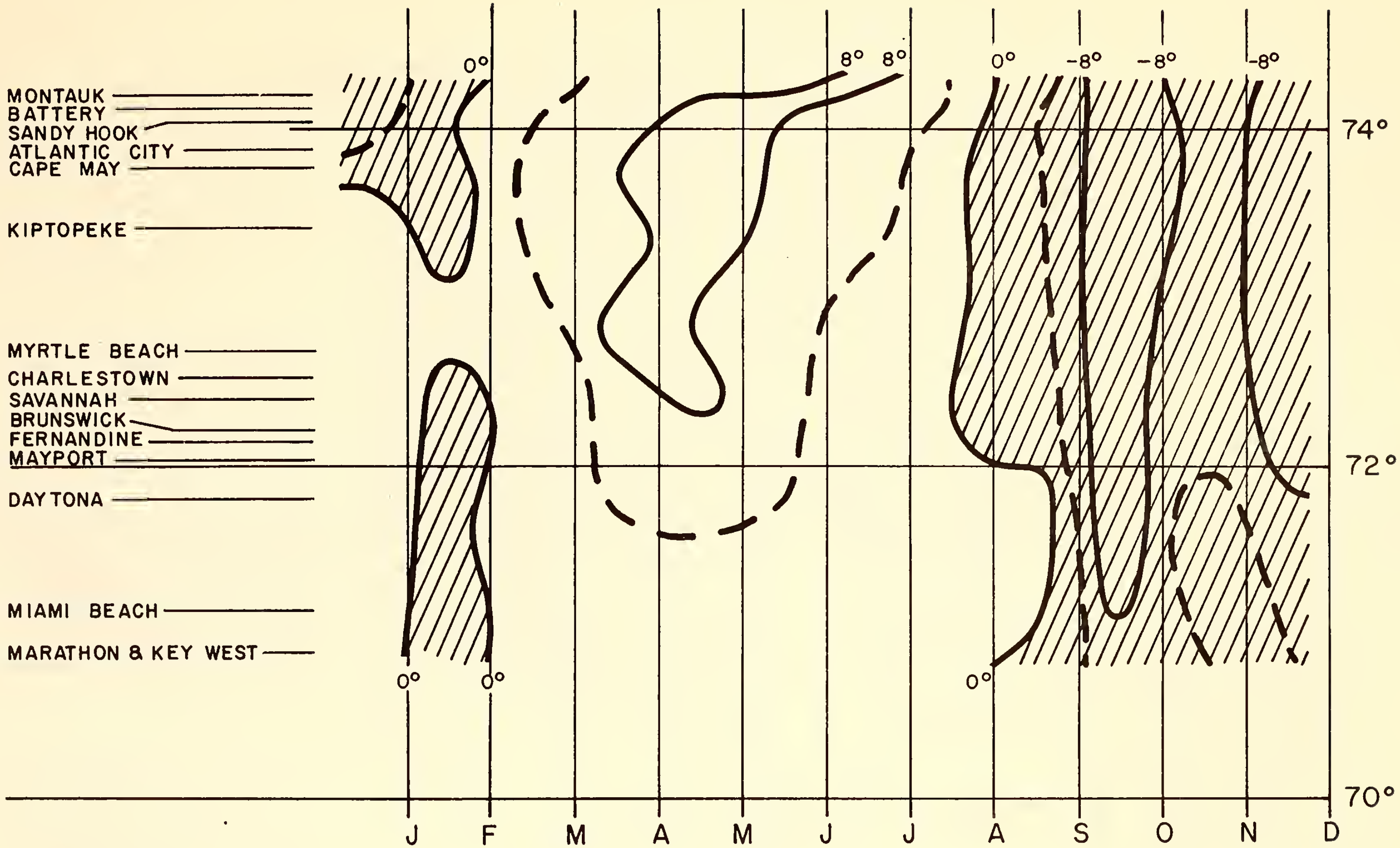

Figure 19.1b Change in mean monthly 1974 temperatures at east coast tide stations, Montauk to Key West. Contour interval is 4°F. Negative values are shaded.

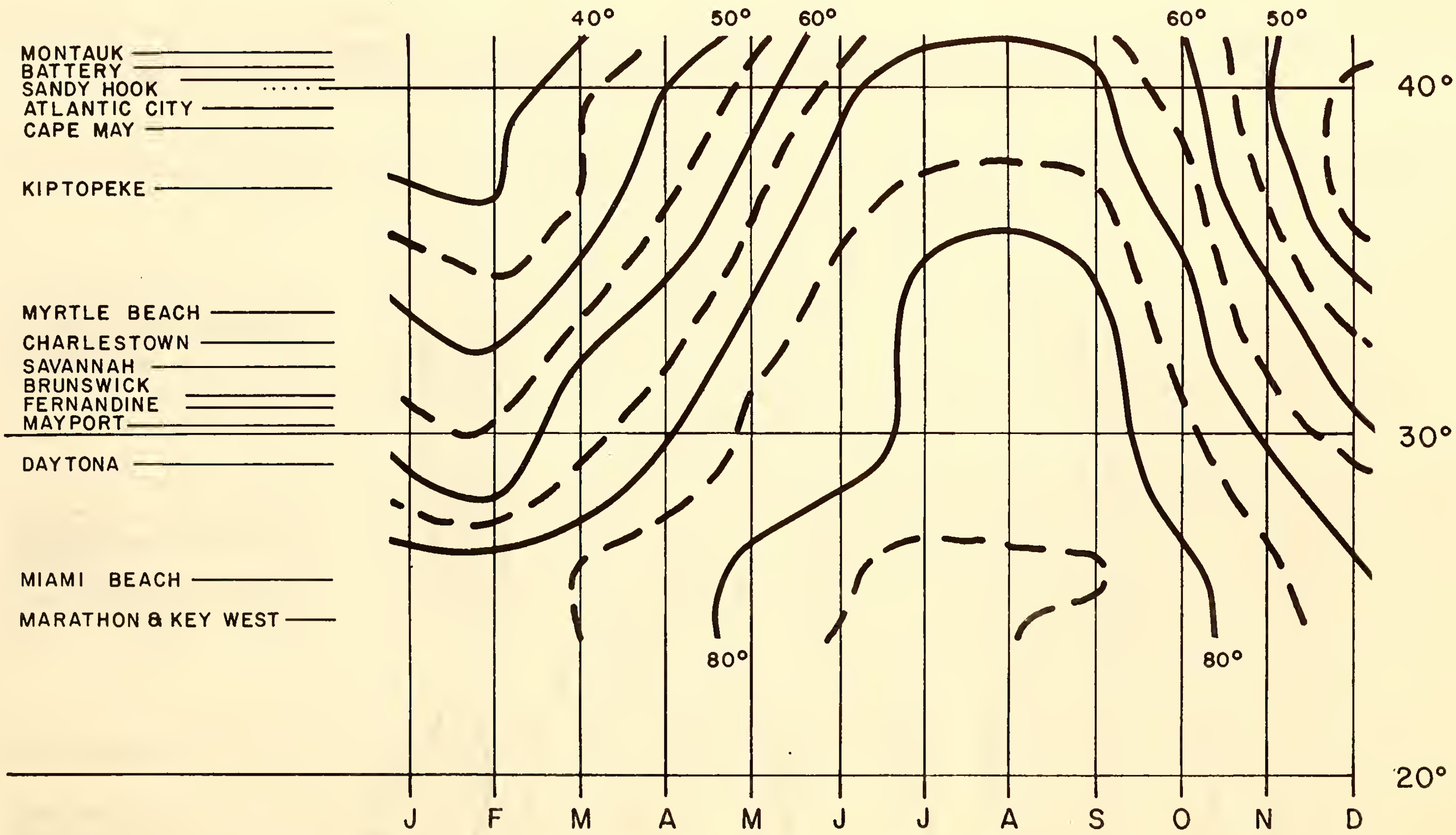

Figure 19.2a Mean monthly 1973 temperatures at east coast tide stations, Montauk to Key West.

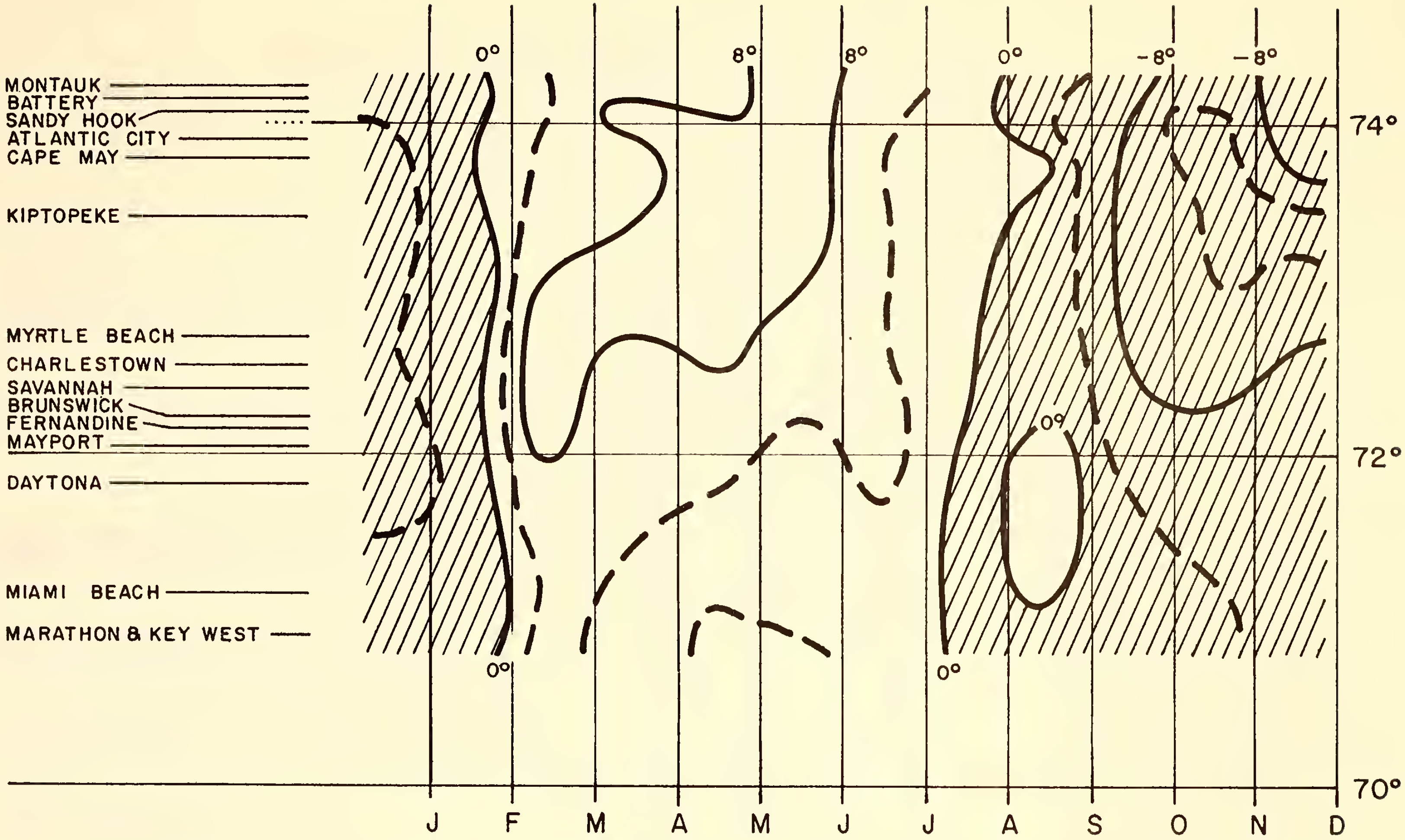

Figure 19.2b Change in mean monthly 1973 temperatures at east coast tide stations, Montauk to Key West.

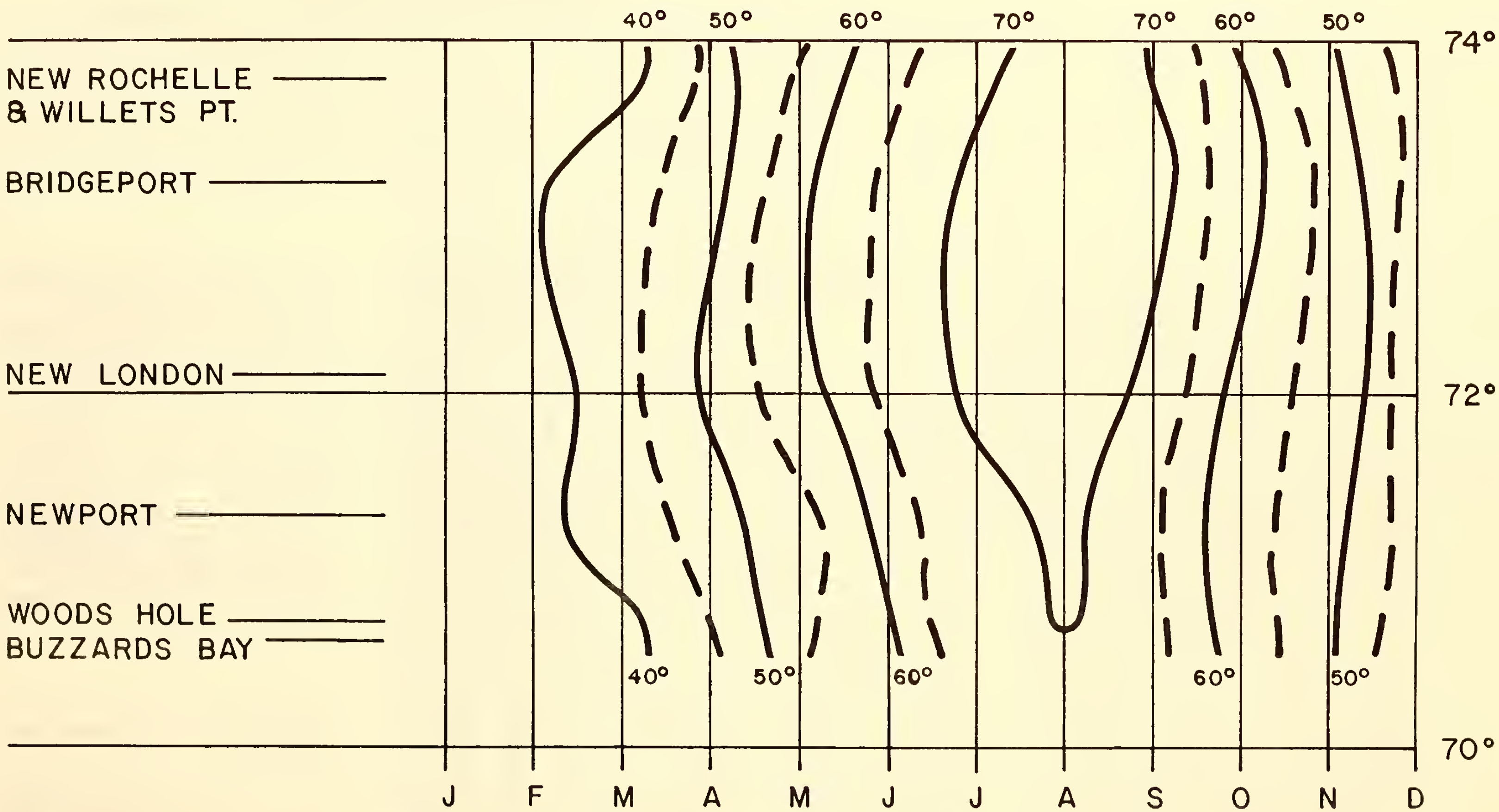

Figure 19.3a Mean monthly 1974 temperatures at Long Island Sound tide stations, Buzzards Bay to New Rochelle.

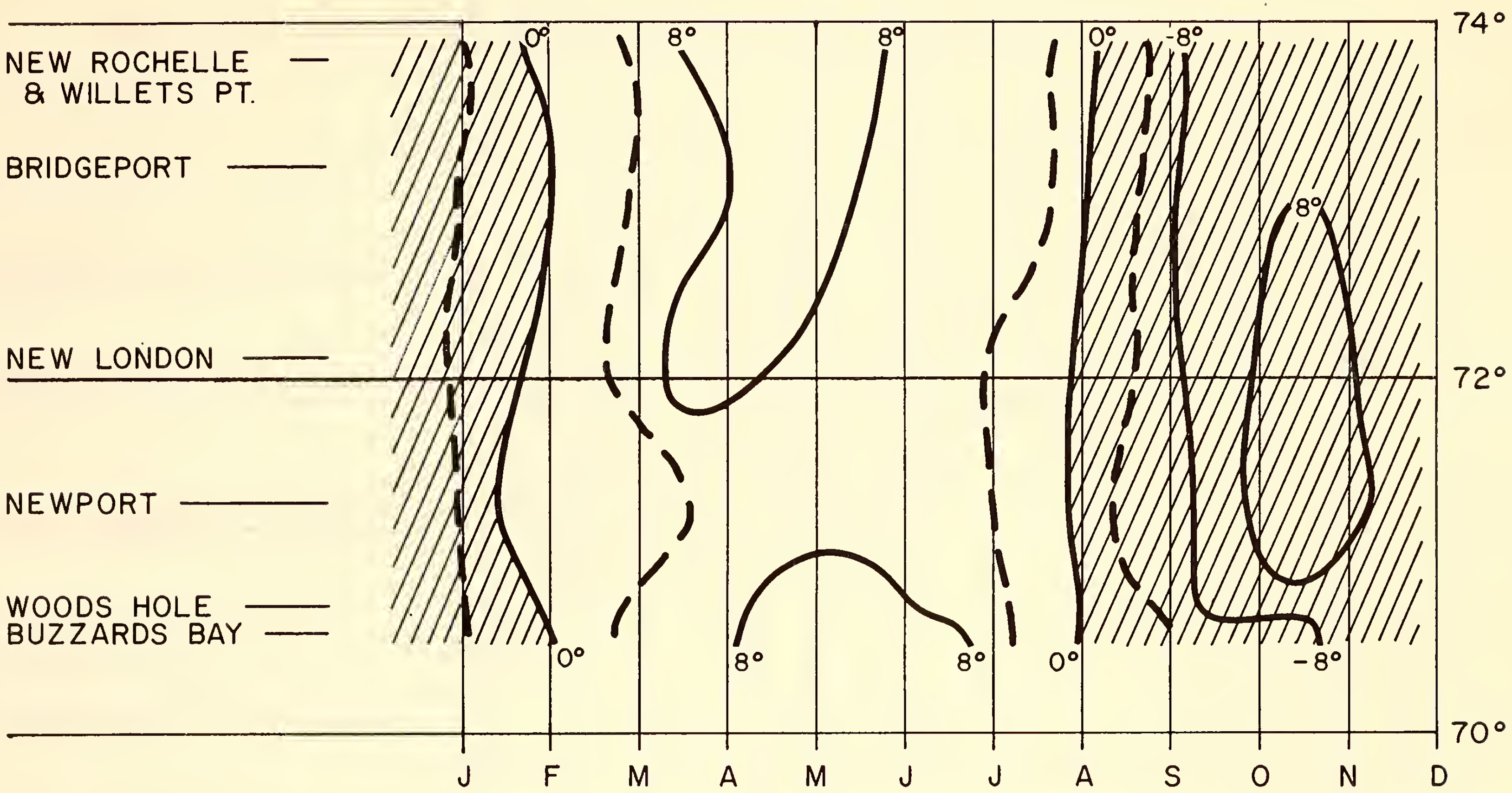

Figure 19.3b Change in mean monthly 1974 temperatures at Long Island Sound tide stations, Buzzards Bay to New Rochelle.

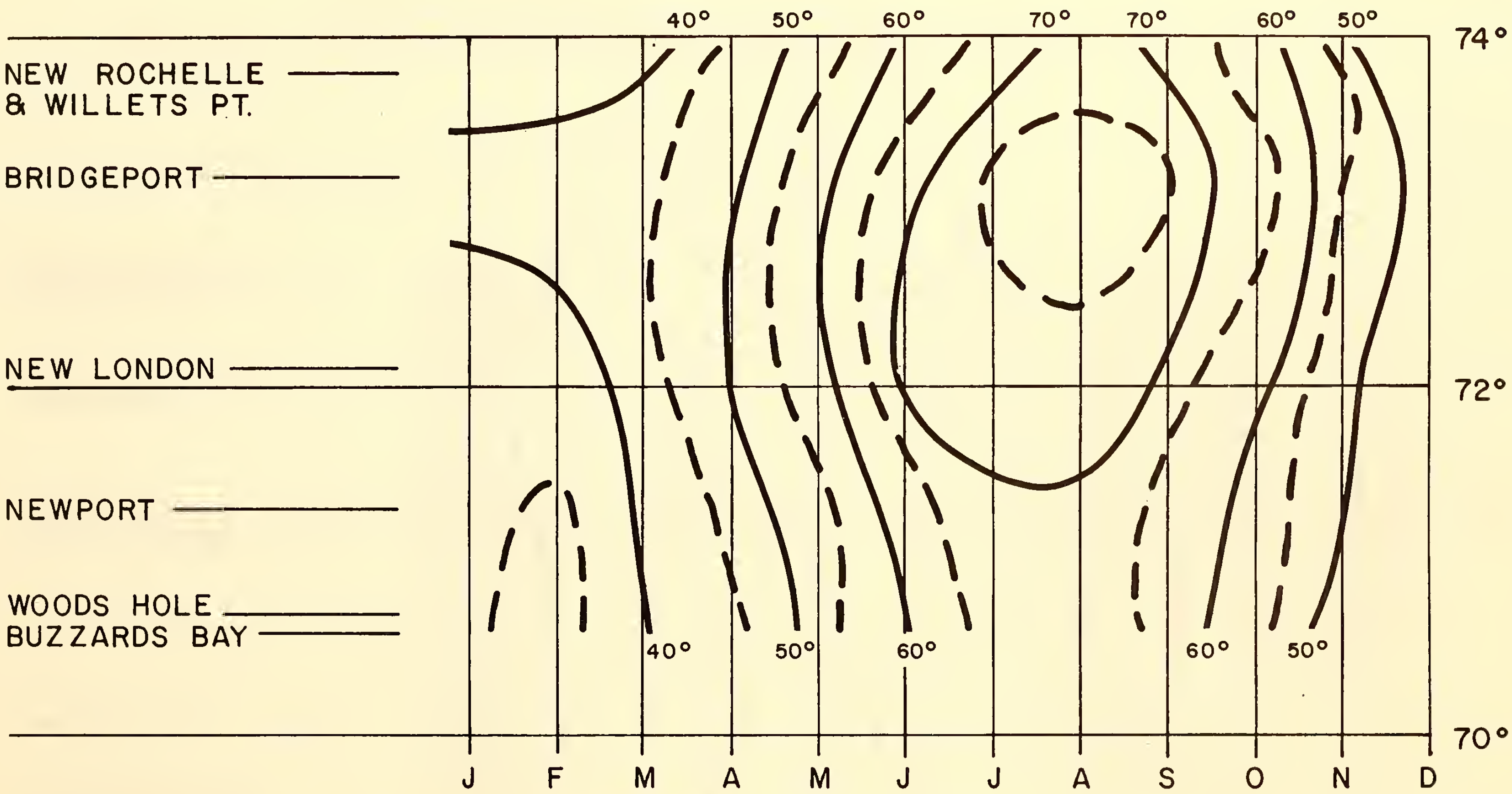

Figure 19.4a Mean monthly 1973 temperatures at Long Island tide stations, Buzzards Bay to New Rochelle.

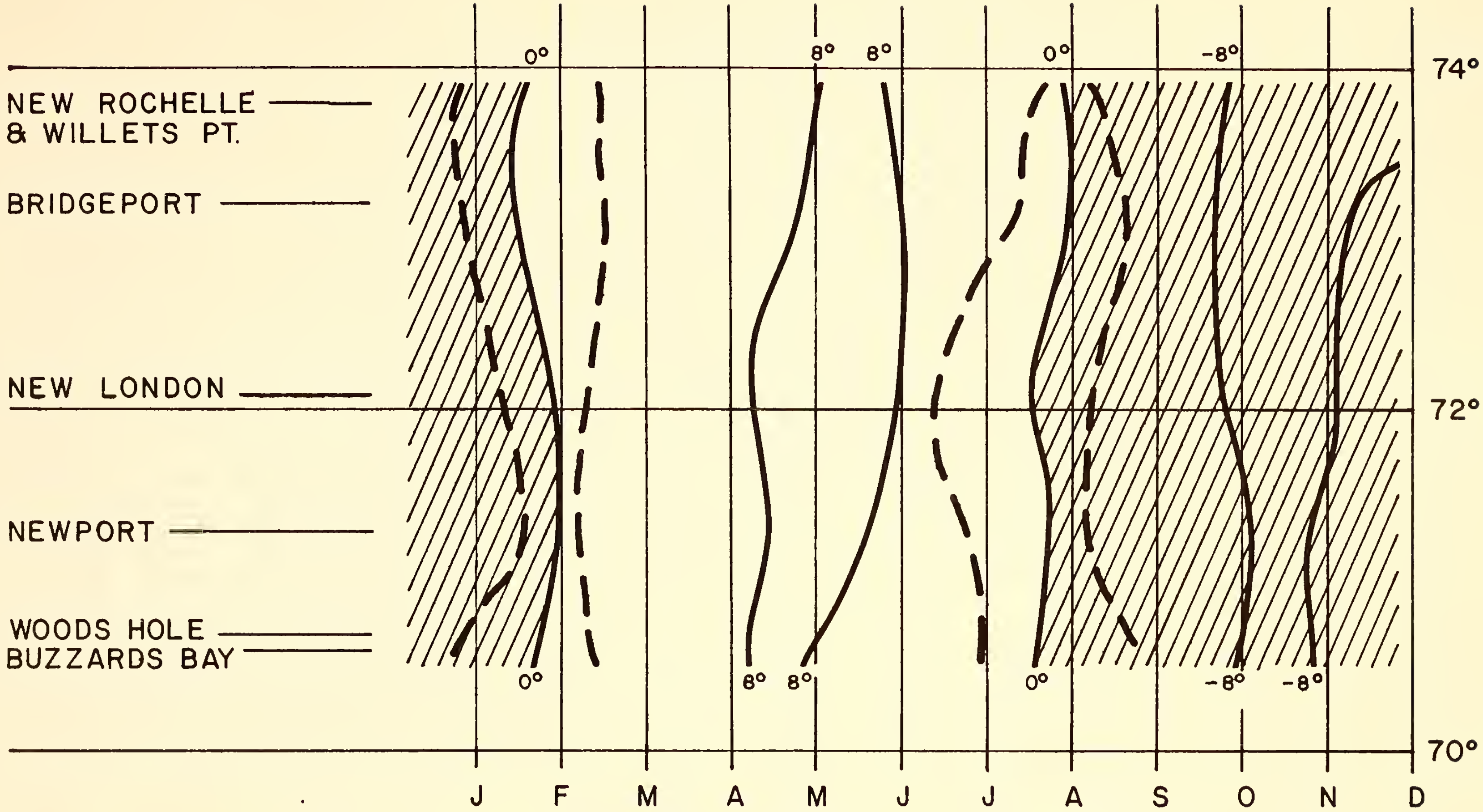

Figure 19.4b Change in mean monthly 1973 temperatures at Long Island Sound tide stations, Buzzards Bay to New Rochelle.

Monthly Maps of Sea Surface Temperature Anomaly in the Northwest Atlantic Ocean and Gulf of Mexico, 1974.

Douglas R. McLain

Pacific Environmental Group, NMFS

ABSTRACT

Sea surface temperature observations taken by merchant, Naval, and other vessels in the area of the Northwest Atlantic Ocean and Gulf of Mexico bounded by the east coast of North America and longitude 60°W and latitude 20°N to 46°N are summarized by month and 1 degree square during 1974.

INTRODUCTION

The Pacific Environmental Group has access to unclassified real-time weather reports received by the U.S. Navy Fleet Numerical Weather Central. These weather reports are available globally and have been stored on magnetic tape since before 1968. This report presents monthly maps of sea surface temperature anomaly based on these reports.

Since 1965 the U.S. Naval Oceanographic Office has published maps of sea surface temperature and its anomaly monthly in the publication "Gulf Stream." The maps presented in this report differ from those of the "Gulf Stream" in several ways. First, these maps include the Gulf of Mexico and a larger area of the Caribbean Sea than those of the "Gulf Stream." The area covered is that portion of the Northwest Atlantic Ocean bounded by the coast of North America, 60° west longitude and

20° and 46° north latitude. The maps of the "Gulf Stream" cover the region bounded by the coast and longitude 54°W and latitude 24°N to 45°N. Second, the maps are part of a series of such maps that can be generated in a consistent manner back to 1948. McLain, Mayo, and Oven[1/] have developed such maps for the period 1948 to 1967 based on historical data and are now updating the series to 1972. Third, the actual observations used for making these and the "Gulf Stream" maps, although both being made by merchant and naval vessels, are not completely identical sets and thus differences in the number of observations in particular areas and months exist between the two series of maps. Finally, these maps are based on a 20 year reference period, 1948 to 1967, which was chosen as a recent 20-year period in which numerous observations were available. McLain, Mayo and Oven used this same reference period whereas the "Gulf Stream" maps are based on a historical mean of approximately 100 years.

DATA PROCESSING

The maps were constructed from observations of sea surface temperature received in "real-time" from merchant, naval, and other vessels by Fleet Numerical Weather Central. These reports were edited by a two stage filter similar to that used by

1/ Manuscript submitted for publication as NOAA Technical Report NMFS SSRF.

McLain, Mayo, and Oven for historical data. In the first stage all observations less than -5.0°C or greater than +35.0° were rejected to eliminate obviously erroneous values. Second, reports greater than 9°C from the 1948-67 monthly mean were rejected. Means of sea surface temperature by 1° square of longitude and latitude and anomalies from the 1948-67 mean were then computed. The anomalies were then plotted on an electrostatic plotter with the 1948-67 mean and the number of reports in each 1° square. Following the convention of the "Gulf Stream" maps, values were plotted only if there were 4 or more observations in each square. The squares were shaded for anomalies of 1.0°C or greater and for -1.0°C or less to emphasize the patterns of sea temperature anomaly.

SOURCES OF ERROR

As mentioned by McLain, Mayo, and Oven, there are a number of potential sources of bias and error associated with the sea surface temperature observations from ships of opportunity. Some of these errors are as follows:

1) Ships tend to avoid areas of bad weather, consequently, the observations are biased towards areas of fair weather conditions. This bias has become more important in recent years as marine weather reporting, forecasting, and optimum track ship routing have improved.

2) The observations are not randomly distributed over large ocean areas but instead are concentrated along shipping lanes. Thus observations are much more dense off New York

than in the infrequently travelled western portion of the Gulf of Mexico. Also the data may be biased due to varying distribution of observations in time and space within each 1 degree square.

3) Most of the observations of sea surface temperature are "injection temperatures," that is, they are made with a thermometer in the ship's main cooling water intake. Thus they are subject to instrument calibration error and to warming of the intake water in the engine room. Using data from 12 selected ships, Saur (1963) studied these errors and found that the injection temperatures averaged about 1.2°F higher than surface water temperatures taken by a bucket thermometer.

DISCUSSION

Elsewhere in this Status of the Environment Report, Namias and Dickson discuss the large scale atmospheric circulation during 1974 and its effects on sea surface temperature. They show that the sea surface temperature was generally warmer than normal throughout 1974 along the East Coast of North America. They attributed this to "the warm southerly anomaly wind prevailing along the western flank of the strengthened Bermuda High, lessening the transfer of sensible and latent heat from the ocean, while the anticyclonic cell itself is positioned to minimize the deep outbreaks of polar continental air from North America to the western Atlantic during the cold season." The "Gulf Stream" Monthly Summaries published by the Naval Oceanographic Office indicate that positive temperature anomalies in the Slope Water northeast of Cape Hatteras out to about 70°W were associated with displacements of the Gulf Stream to the north of its normal position during all months of 1974. One could speculate that the northerly displacements of the Gulf Stream might be related to an increased strength or transport of the stream which could have in turn been related to unusually strong wind stress over the North Atlantic. Namias and Dickson and Wagner[2/] indicate that the Icelandic Low and Bermuda High circulation systems were unusually intense during 1974 which led to abnormally high index circulation over the North Atlantic. Such a high index circulation would cause increased wind stress over the North Atlantic and increase the advection of water around the North Atlantic Gyre.

2/ WAGNER, A.J.

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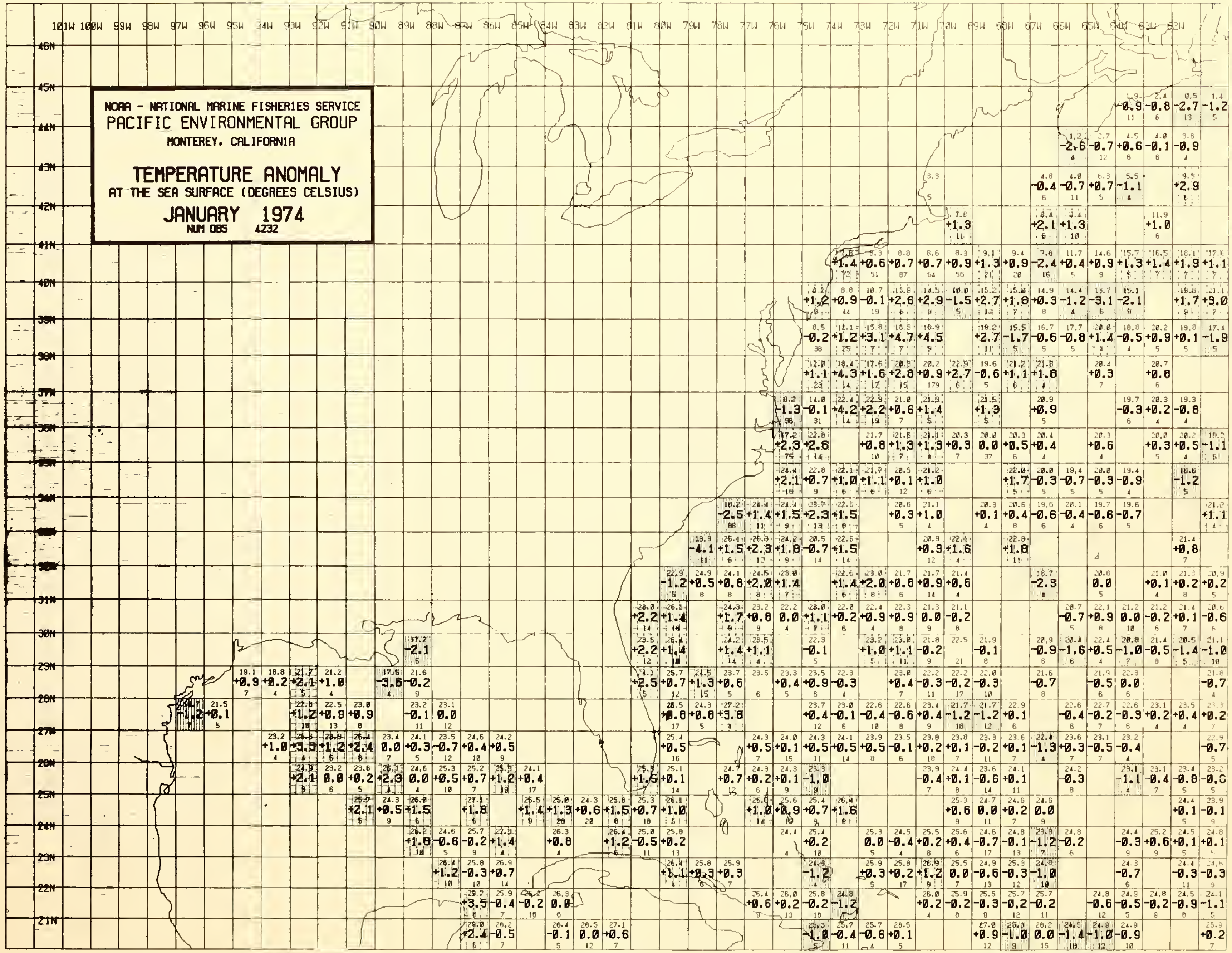
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PACIFIC ENVIRONMENTAL GROUP
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JANUARY 1974
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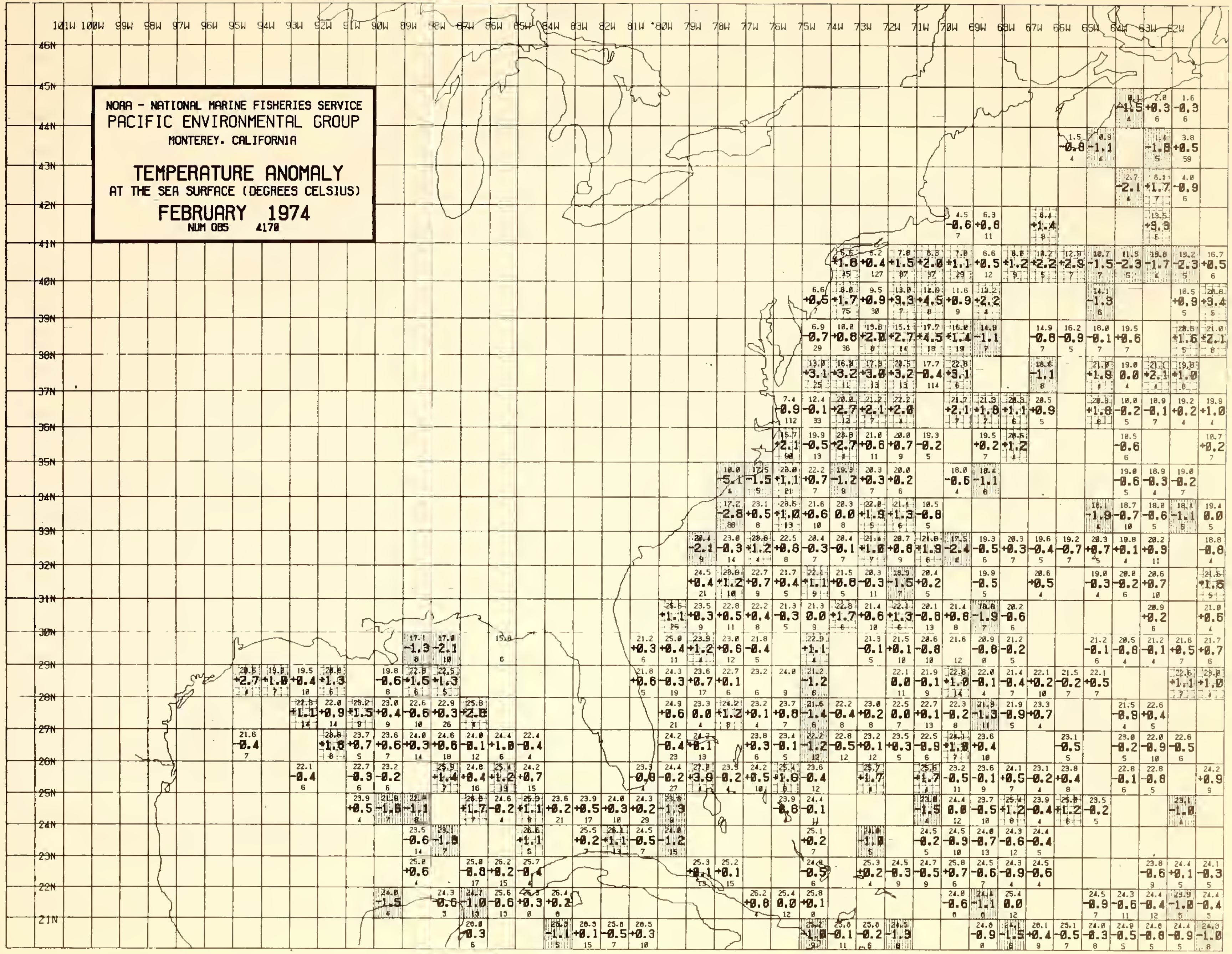
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MONTEREY. CALIFORNIA
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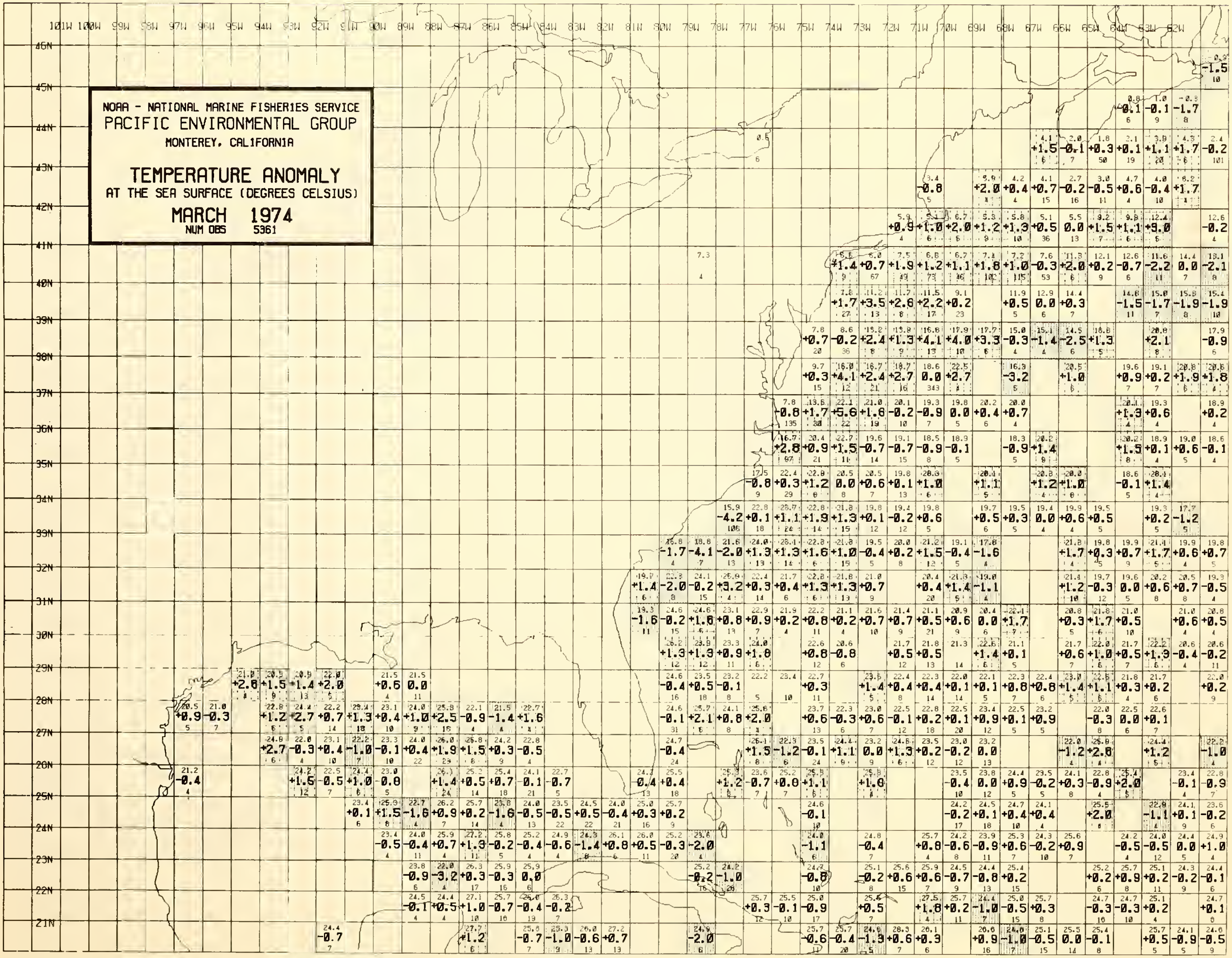
NOAA - NATIONAL MARINE FISHERIES SERVICE
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MONTEREY, CALIFORNIA
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MARCH 1974
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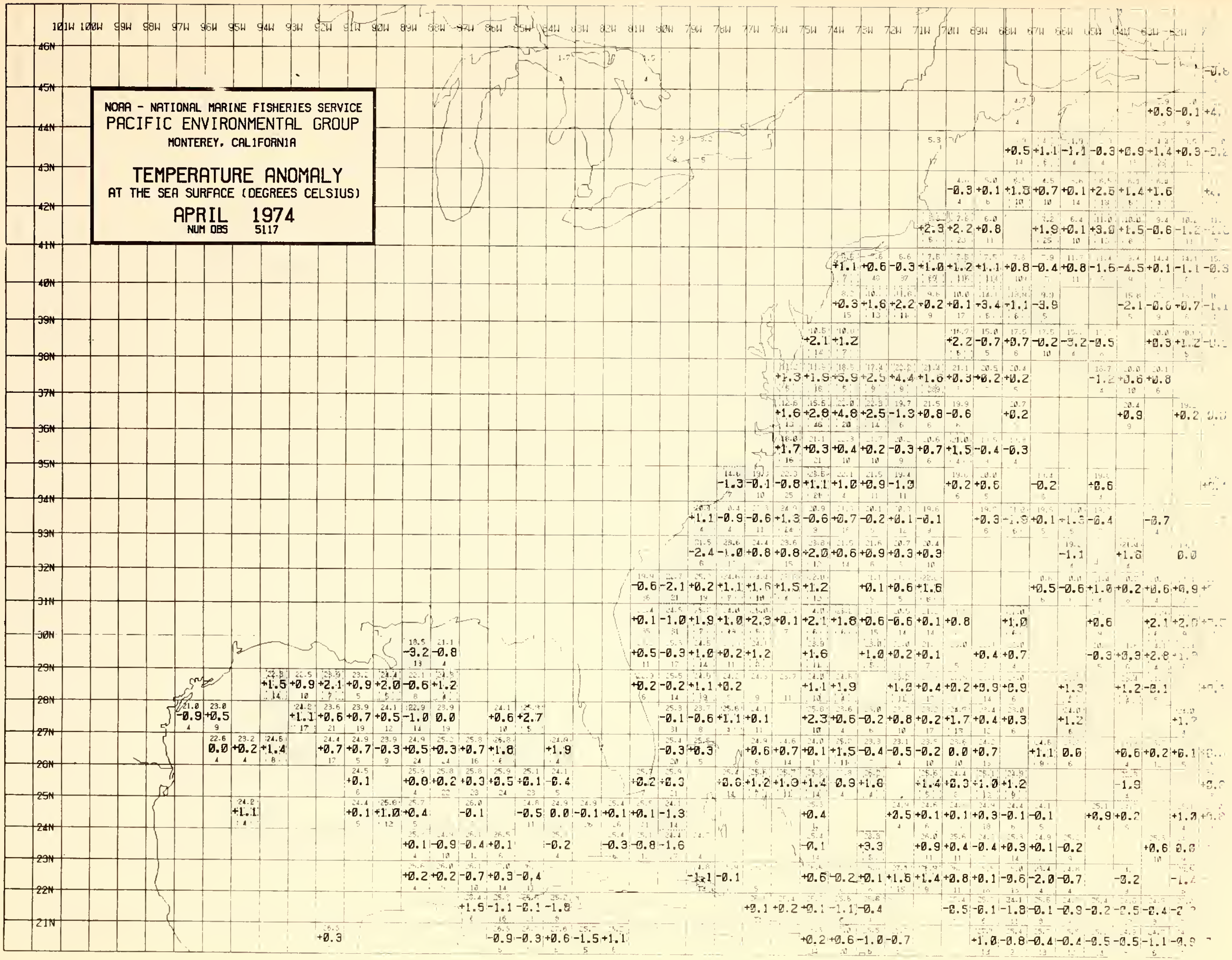

NOAA - NATIONAL MARINE FISHERIES SERVICE
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MONTEREY, CALIFORNIA
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AT THE SEA SURFACE (DEGREES CELSIUS)
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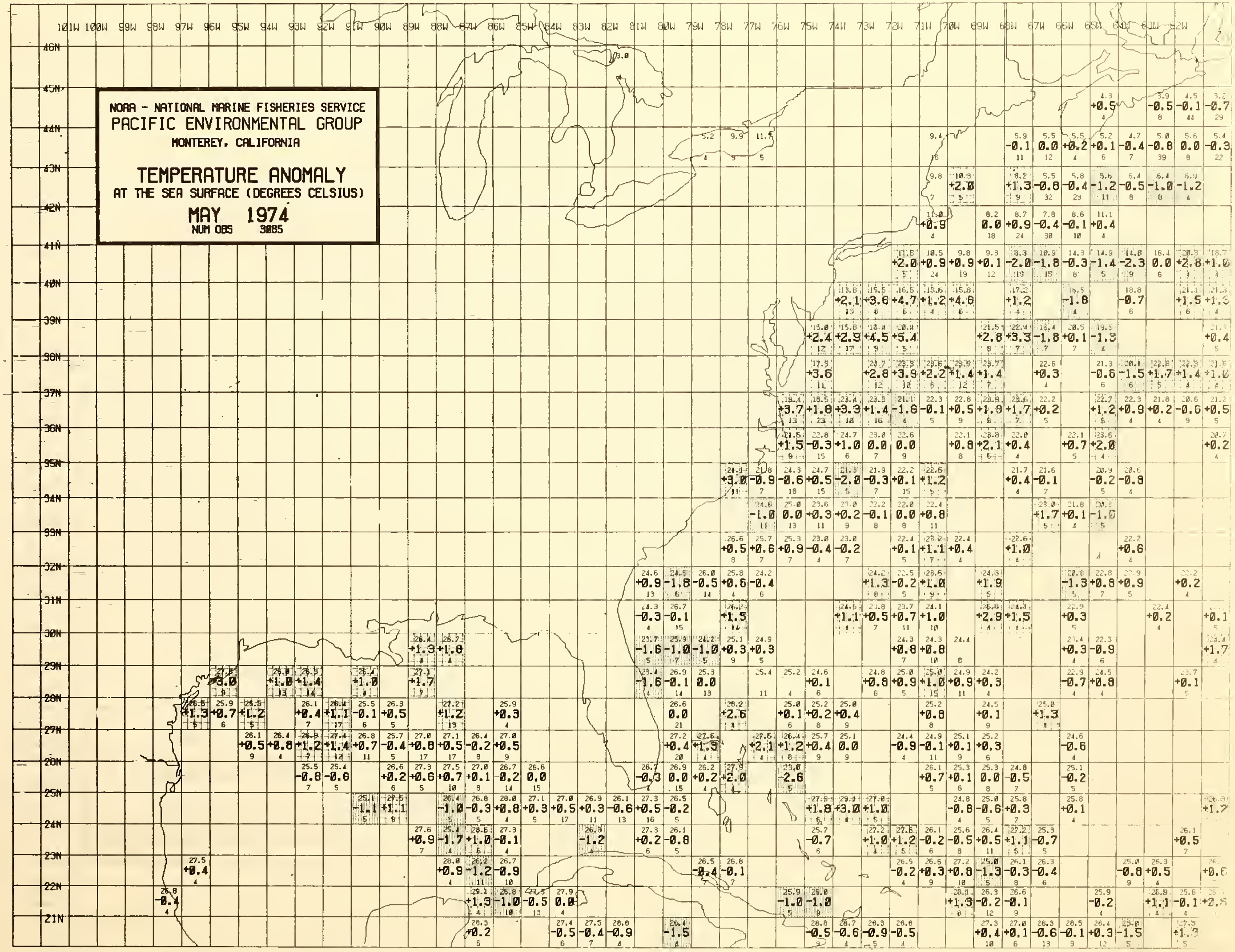

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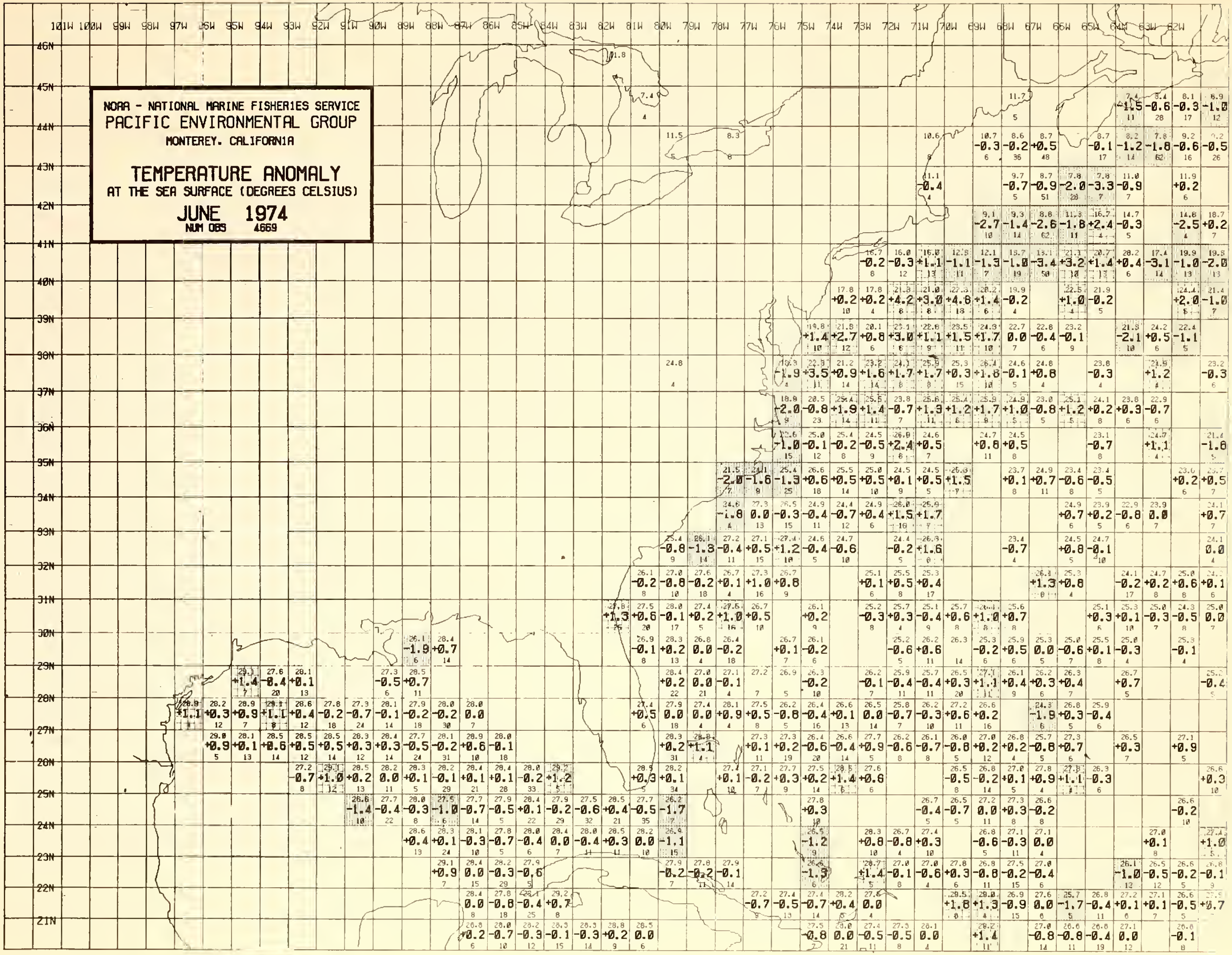

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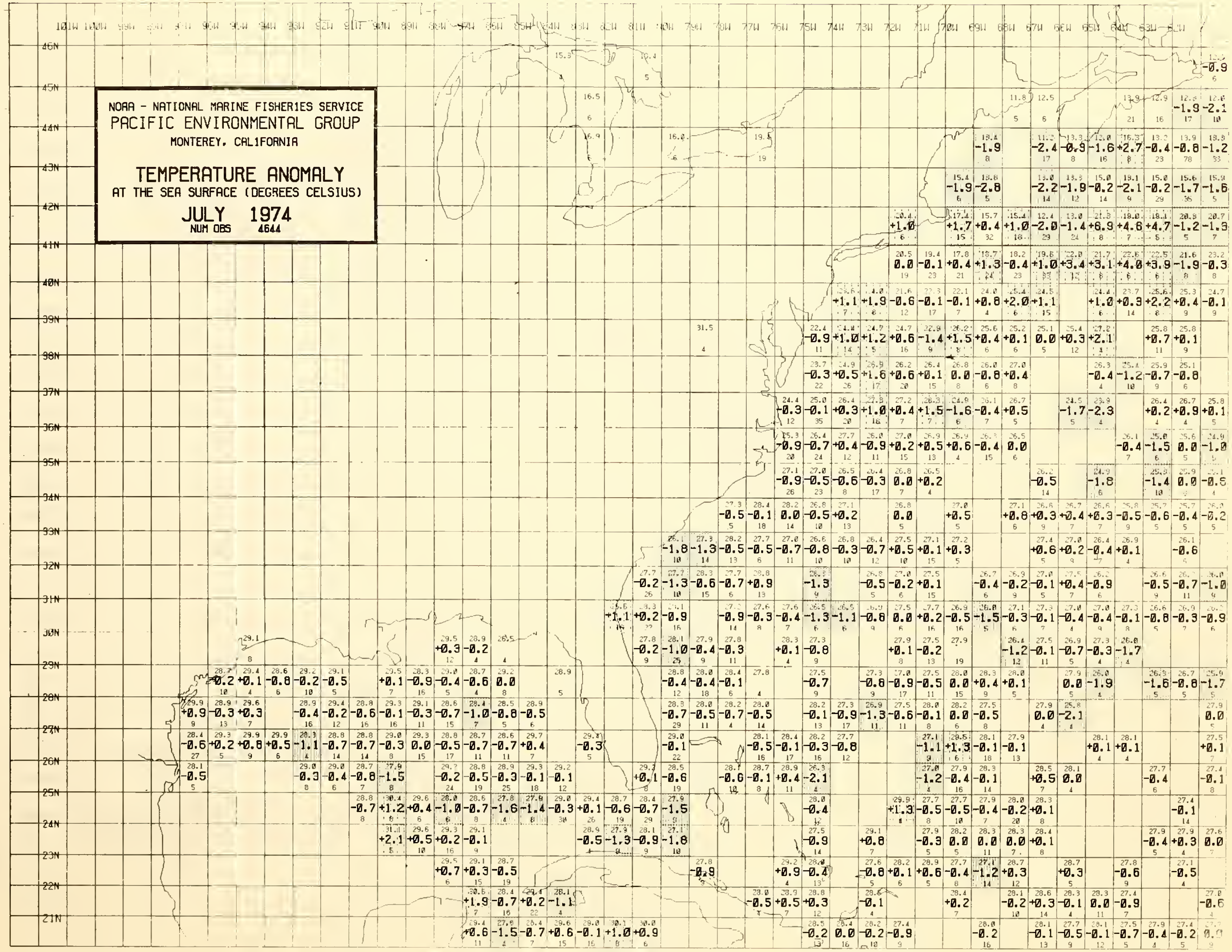
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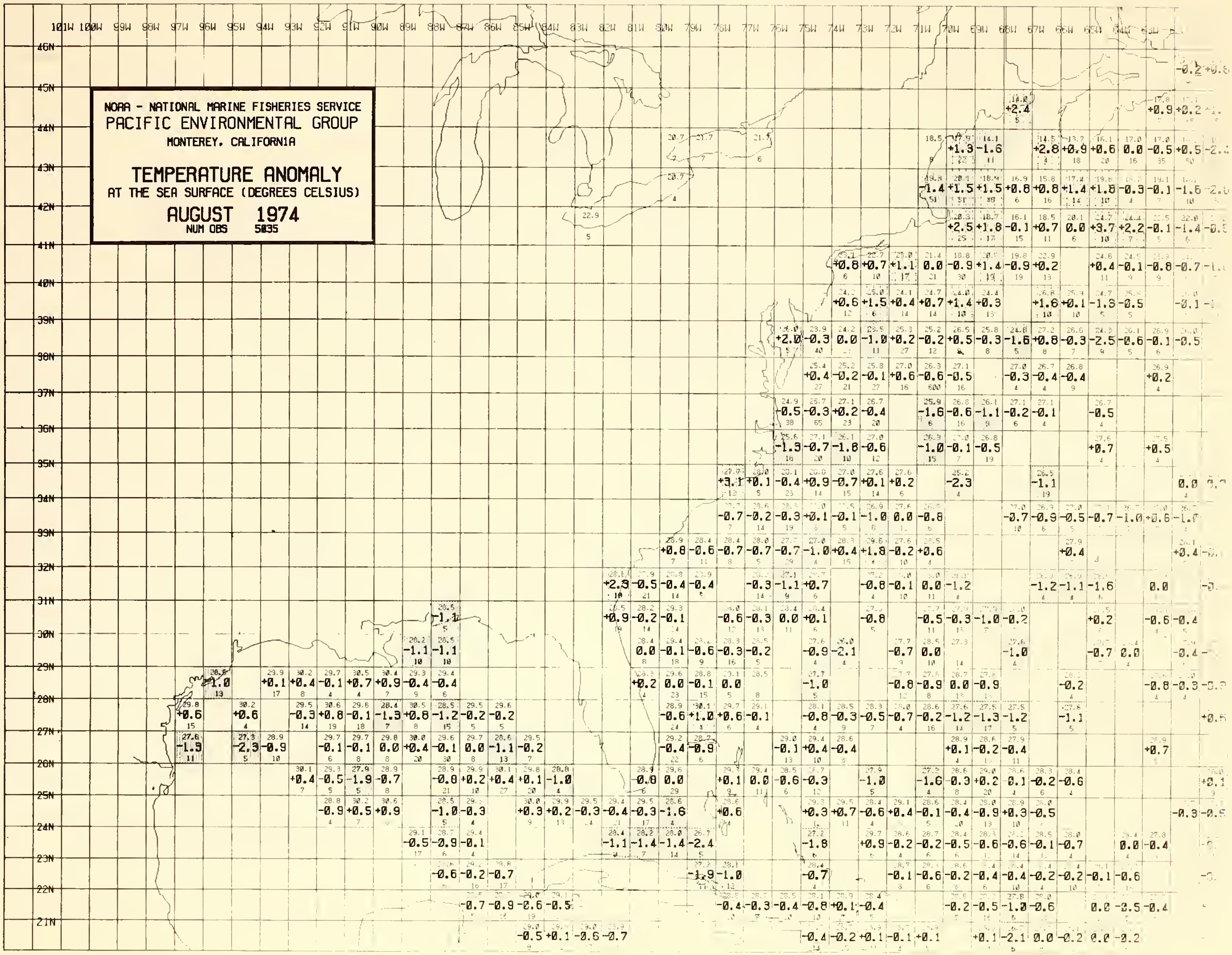
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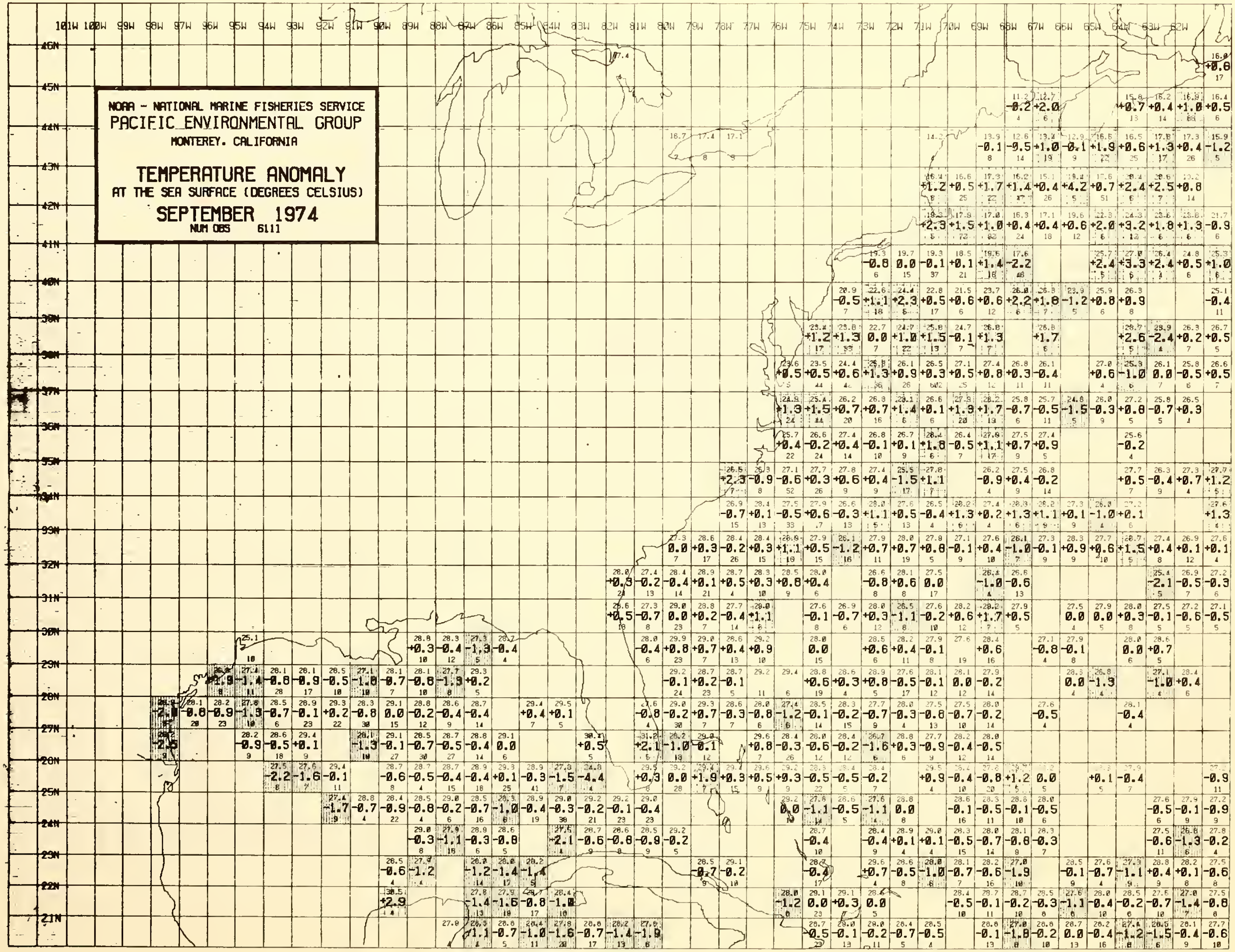
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SEPTEMBER 1974
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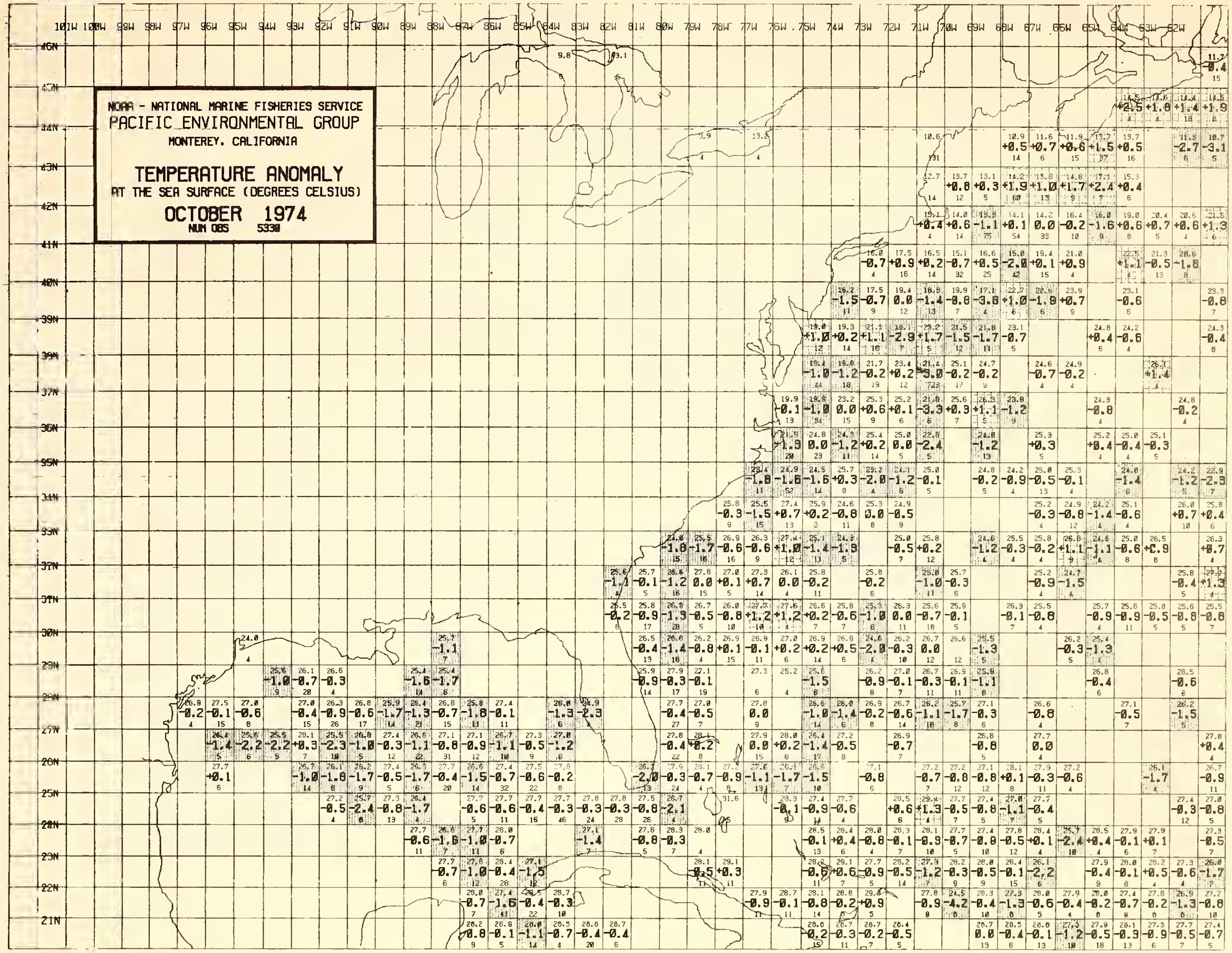
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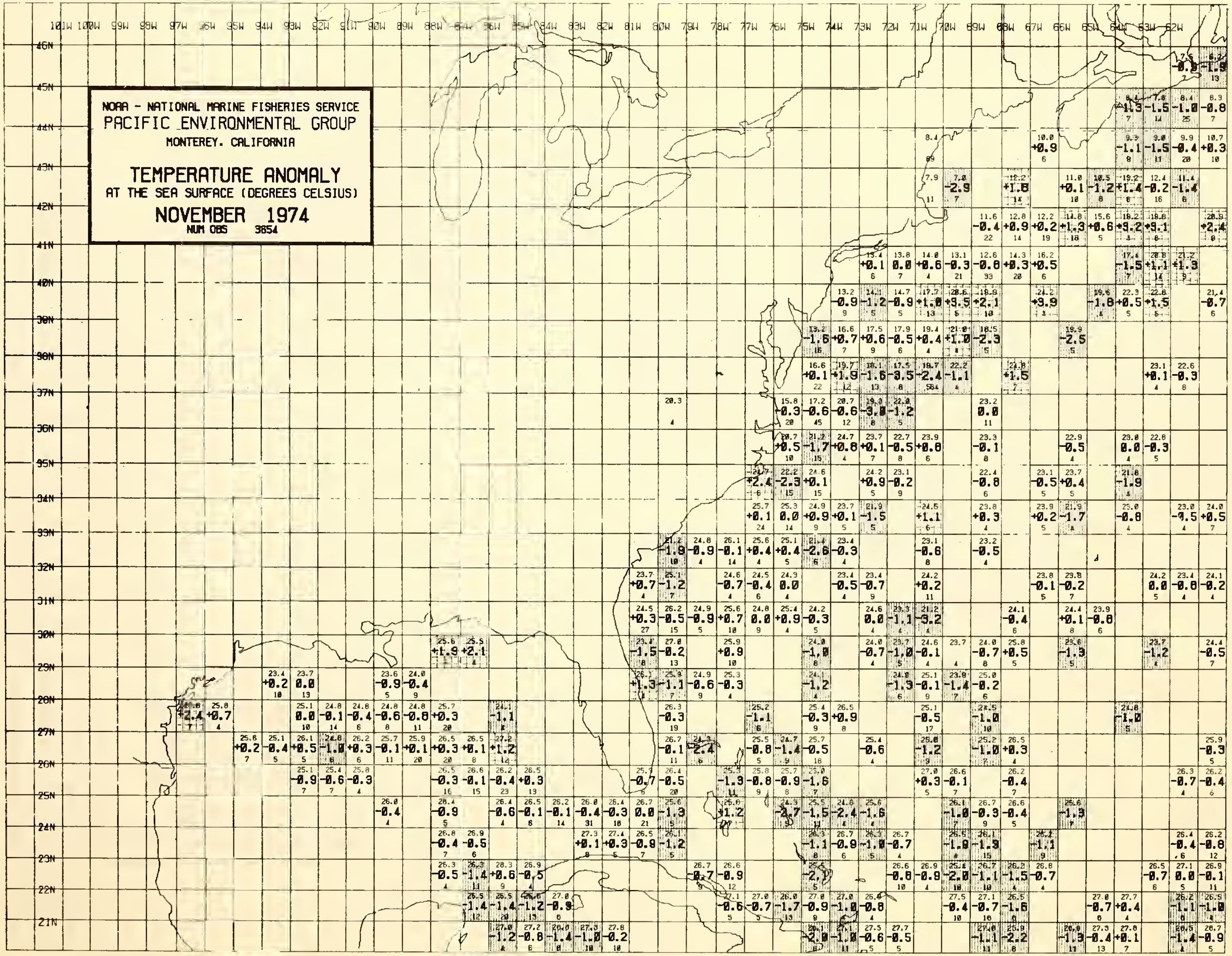
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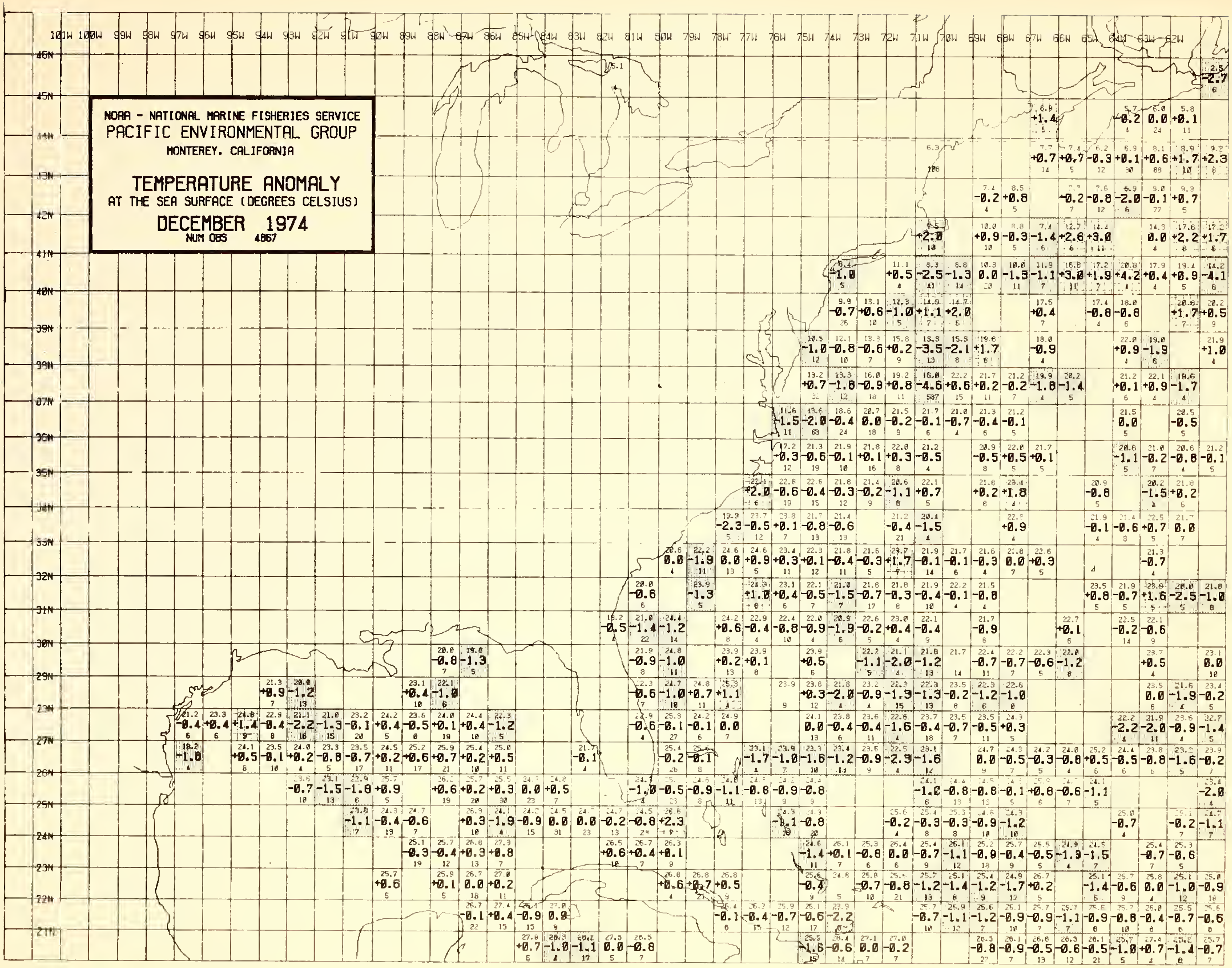
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MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
DECEMBER 1974
NUM OBS 4067

Environmental Conditions in the Gulf of Mexico and Western North Atlantic as Observed from NMFS/MARAD Ships of Opportunity for 1974

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Atlantic Environmental Group
National Marine Fisheries Service

INTRODUCTION

The purpose of the NMFS Ship of Opportunity Program (SOOP) is to monitor the major fluctuations of the Gulf Stream, Shelf Water-Slope Water front and bottom water cold cell in the western North Atlantic and the Loop Current and any associated eddies in the Gulf of Mexico. NMFS scientists believe that the distribution and abundance of resource species are influenced by variations in temperature, salinity, and nutrients. Changes in the environment can manifest themselves in the form of early or late spawning, onshore or offshore migrations of pelagic or benthic species, or concentration or dispersal of various fish populations. Monitoring the perturbations of the various frontal features (i.e. the intrusion of Shelf Water onto southeastern Georges Bank, etc.) can be a useful aid to NMFS scientists in predicting year class strengths. The monitoring of the various eddies (anticyclonic-clockwise and cyclonic-counterclockwise) may provide NMFS scientists with a hint as to the basic productivity of an area. Cyclonic, cold core, eddies provide discrete areas of upwelling. These areas of upwelling bring more nutrient rich subsurface waters into the photic zone where photosynthesis can commence. These eddies also provide an area of divergence at the surface thereby enlarging the area available for photosynthetic activity.

Anticyclonic, warm core, eddies provide an area of convergence at the surface thereby concentrating the nutrients, phytoplankton and zooplankton. Therefore, anticyclonic eddies act as entrapment areas for the planktonic forms and cyclonic eddies act as areas of surface enrichment. Because these eddies are constantly on the move, the monitoring of their migrations and extent becomes important.

TRANSECT ANALYSIS

Gulf of Mexico

Loop Current

In 1974 the Loop Current was transected on 7 occasions (Table 21.1) ships. There were two crossings in March (fig.21.1)one in April (fig.21.2) two in May (fig.21.3)and one each in June (fig.21.4)and July (fig.21.5).

Utilizing the criterion of 20°C at 125 m as the left edge of the Loop Current (Maul, personal communication) the position of the front can

SOOP 1974

LOOP CURRENT CROSSINGS SOOP 1974

Figure	Ship	Station #	Date
1	DELTA SUD	20-23	March 8-9
1	DELTA NORTE	11-15	March 21-23
2	DELTA SUD	28-31	April 15-17
3	DELTA SUD	40-32	May 21
3	DELTA SUD	22-24	May 27-29
4	DELTA SUD	9-2	June 28-29
5	DELTA SUD	17-20	July 7-8

TABLE 21.1

be monitored from XBT data. Most migrations of the Loop Current edge ranged randomly between 22°N and 24°N latitude. Movements of more than 1° of latitude in less than 2 weeks was not uncommon. One migration of about 90 nm (167 km) occurred within 9 days, between June 28 (fig.21.4 and July 7 (fig. 21.5).

The Loop Current was crossed by the Delta Sud on March 9 at 23°15'N latitude at station 23 (fig.21.1). Again on March 23 at 22°30'N the Delta Norte crossed the Loop Current (fig. 21.1).

In April (fig.21.2)a crossing of the Loop Current by the Delta Sud determined the front to be at 22°N.

In May (fig.21.3)the Loop Current appeared as a broad flowing current. At this time the front's position had intruded up to 24°N latitude.

Again in May (fig.21.3),the Delta Sud crossed the Loop Current at 23°N.

In June (fig.21.4),the Loop Current again appeared as a broad flowing current. The main front (20°C and 125 meters) showed up at about 24°N.

In July (fig.21.5),the Loop Current was crossed by the Delta Sud at 22°30'N.

Eddies

In 1974 the SOOP ships transected eddies on 19 occasions (table 21.2) all of which were anticyclonic. Eddies were transected in March, April, May, June, July, August and November (figs.21.1-6). The diameters of these eddies range from about 75 nm to 335 nm and ranged in depth from 200 to 700 m. Some eddies were transected more than once. One anticyclonic eddy, in particular was easy to track because it had a subsurface signature in the form of a peak in the 26° isotherm that was opposite to the trend of the rest of the isotherms. This peak also happened to occur at the center of the eddy. This eddy was transected on May 21 (fig21.3) July 7 (fig.21.5)by the Delta Sud and July 21 (fig.21.5)by the Delta Norte and migrated in position from 26°24'N, 87°52'W (fig21.3) to 24°55'N, 88°55'W (fig21.5)to 25°26'N, 89°44'W (fig21.5). On all crossings the eddy structure extended to depths of greater than 600 m. The eddy moved 140 nm in 2 months in a southwesterly direction or about 2.3 nm/day.

Table 21.2 - Location and characteristics of eddies transected in the Gulf of Mexico by SOOP vessels in 1974.

Figure	Ship	Station # / Coordinates		Date	Depth(m)	Diameter(nm/km)	Direction of Flow
1	Delta Sud	12	26°56'N 91°33'W	March 8-9	> 500	170 (315)	anticyclonic
		16	25°08'N 89°21'W		> 500	170 (315)	anticyclonic
		17	24°56'N 89°05'W		> 500	120 (222)	anticyclonic
		20	23°40'N 87°32'W		> 500	120 (222)	anticyclonic
1	Delta Norte	1	27°52'N 92°51'W	March 21-23	> 600	200 (370)	anticyclonic
		5	25°09'N 89°47'W		> 600	200 (370)	anticyclonic
		6	24°50'N 89°28'W		> 700	175 (324)	anticyclonic
		11	22°55'N 87°05'W		> 700	175 (324)	anticyclonic
2	Delta Sud	11	27°01'N 91°51'W	April 15-17	> 600	95 (176)	anticyclonic
		16	26°00'N 90°29'W		> 600	95 (176)	anticyclonic
		16	26°00'N 90°29'W		> 600	290 (537)	anticyclonic
		28	22°46'N 86°30'W		> 600	290 (537)	anticyclonic
3	Delta Sud	40	24°39'N 86°51'W	May 21	600	245 (453)	anticyclonic
		49	28°09'N 88°48'W		600	245 (453)	anticyclonic

Table 21.2 (Cont'd)

Figure	Ship	Station # / Coordinates			Date	Depth(m)	Diameter(nm/km)	Direction of Flow
3	Delta Sud	4	27°28'N	92°16'W	May 27-29	> 600	120 (222)	anticyclonic
		9	26°10'N	90°48'W		> 600	120 (222)	anticyclonic
		9	26°10'N	90°48'W		> 600	300 (556)	anticyclonic
		22	23°10'N	86°55'W		> 600	300 (556)	anticyclonic
4	Delta Sud	9	25°41'N	87°08'W	June 28-29	> 500	175 (324)	anticyclonic
		17	28°08'N	88°52'W		> 500	175 (324)	anticyclonic
5	Delta Sud	4	27°17'N	91°44'W	July 6-7	> 600	335 (621)	anticyclonic
		14	23°30'N	87°18'W		> 600	335 (621)	anticyclonic
5	Delta Norte	8	27°48'N	92°44'W	July 20-21	> 600	140 (259)	anticyclonic
		13	26°17'N	90°54'W		> 600	140 (259)	anticyclonic
		13	26°17'N	90°54'W		> 700	195 (361)	anticyclonic
		22	24°17'N	88°17'W		> 700	195 (361)	anticyclonic
6	Mayaquez	1	29°01'N	88°44'W	August 17-18	> 600	165 (306)	anticyclonic
		7	27°22'N	86°41'W		> 600	165 (306)	anticyclonic

Table 21.2 (Cont'd)

Figure	Ship	Station # / Coordinates		Date	Depth(m)	Diameter(nm/km)	Direction of Flow
6	Mayaquez	19	24°24'N 82°39'W	August 25-26	> 700	240 (445)	anticyclonic
		24	26°54'N 85°53'W		> 700	240 (445)	anticyclonic
6	Mayaquez	1	28°44'N 88°26'W	August 28-29	> 600	140 (259)	anticyclonic
		6	27°19'N 86°27'W		> 600	140 (259)	anticyclonic
		6	27°19'N 86°27'W		> 200	150 (278)	anticyclonic
		9	25°37'N 84°22'W		> 200	150 (278)	anticyclonic
6	Delta Sud	10	25°37'N 87°33'W	November 2	> 600	75 (139) *	anticyclonic
		13	26°42'N 88°06'W		> 600	75 (139) *	anticyclonic
6	Delta Sud	21	27°36'N 87°36'W	November 6	> 600	160 (296)	anticyclonic
		26	26°07'N 85°21'W		> 600	160 (296)	anticyclonic

* Only about one-half of this eddy was transected.

On March 8 and 9 the _Delta Sud_ (fig.21.1)crossed two anticyclonic eddies, one at 26°19'N, 91°01'W and the other at 23°52'N, 87°49'W. The horizontal extents at the points of crossing were 170 nm and 120 nm respectively and both extended in depth to greater than 500 meters.

On March 21 and 23 the _Delta Norte_ (fig.21.1)possibly crossed the same two anticyclonic eddies. One was located at 27°02'N, 91°45'W and the other at 23°42'N, 88°07'W. The horizontal extent of these two eddies were 200 nm and 175 nm with depth ranges of 600 meters and 700 meters, respectively.

Between April 15 and 17 the _Delta Sud_ (fig.21.2) again crossed 2 eddies. One was located at 26°25'N, 91°03'W and the other at 24°23'N, 88°19'W. The horizontal extent of these 2 eddies were 95 nm and 290 nm respectively. They both extended to greater than 600 meters depth.

On May 21 the _Delta Sud_ (fig.21.3)crossed an anticyclonic eddy centered at approximately 26°24'N, 87°52'W. The eddy had a horizontal extent of 245 nm and was greater than 600 meters in depth. As previously mentioned, this was the first of three crossings of this particular eddy.

Between May 27 and 29 the _Delta Sud_ (fig.21.3)again crossed 2 anticyclonic eddies. One was centered at 26°44'N and 91°28'W the other was centered at 25°05'N, 89°38'W. The horizontal extent of these 2 eddies were 120 nm and 300 nm respectively. They both extended to greater than 600 meters depth.

On June 28 and 29 the _Delta Sud_ (fig.21.4)crossed an anticyclonic eddy centered at 26°32'N and 87°48'W. The eddy had a horizontal extent of 175 nm and was greater than 500 meters in depth.

On July 6 and 8 the _Delta Sud_ (fig.21.5)crossed an anticyclonic eddy centered at 24°55'N and 88°55'W. The eddy had a horizontal extent of 335 nm and was greater than 600 meters in depth. This was the second crossing of the eddy first mentioned in Figure 21.3.

On July 20 and 21 the _Delta Norte_ (fig.21.3)crossed 2 anticyclonic eddies. One was centered at 26°30'N and 91°09'W, the other was centered at 25°26'N and 89°44'W. They ranged in extent and depth from 140 nm to 195 nm and 600 meters to 700 meters in depth, respectively. The eddy centered at 25°26'N and 89°44'W was the eddy crossed previously in May (fig.21.3)and early July (fig. 21.5).

On August 17 and 18 the _Mayaquez_ (fig.21.6)crossed an anticyclonic eddy centered at 27°35'N and 86°50'W. The eddy had a horizontal extent of 165 nm and was greater than 600 meters in depth.

On August 25 and 26 the Mayaquez (fig.21.6) crossed an anticyclonic eddy centered at 25°48'N and 84°42'W. The eddy had a horizontal extent of 240 nm and was greater than 700 meters in depth.

Low Salinity Surface Water

River runoff along the Gulf coast in the form of low surface salinities (<34.5%) sometimes extended great distances offshore (well beyond the shelf break). In 1974 9 transects of low salinity water were detected. Crossings in March, April, May, June, July and August (figs.21.1-6). showed large variations in the horizontal extent of the low salinity water (table 21.3).

In March (fig.21.1) the Delta Sud crossed through coastal low salinity water. These stations were located on the continental shelf in water less than 50 m in depth. The offshore extent of the low salinity water was 50 nm.

In April (fig.21.2) the Delta Sud crossed through coastal water as low as 24.5 °/₀₀. These stations were, again, on the continental shelf in water less than 50 meters in depth. The offshore extent of the low salinity water was 70 nm.

In May (fig.21.3) the Delta Sud crossed through coastal water as low as 29.0 °/₀₀. These stations were located at the shelf break (100 meters depth). The offshore extent of the low salinity water was 70 nm and stopped at the interface (front) of an anticyclonic eddy.

In June (fig.21.4) the Delta Sud crossed through low salinity water less than 32 °/₀₀. The stations were located in water greater than 500 meters. The offshore extent of the low salinity water was 90 nm and, again, was stopped at the interface of an anticyclonic eddy that was transporting higher salinity oceanic water northward.

In July (fig.21.3) the Delta Sud crossed through coastal water as low as 28.3 °/₀₀. Stations 1 and 2 were on the continental shelf but station 3 was in deep water. The offshore extent of the low salinity water was 195 nm and stopped, again, at the interface of an anticyclonic eddy. This was the same eddy as described in Figure 21.3. The westward movement of the eddy had apparently allowed the lower salinity water to extend further out to sea.

Again, in July (fig.21.5) the Delta Norte crossed through coastal low salinity water less than 29 °/₀₀. These stations extended from the continental shelf to waters greater than 650 meters in depth. The offshore extent of the low salinity water was 230 nm and, again, stopped at the interface of an anticyclonic eddy.

LOW SALINITY WATER < 34.5 ‰ SOOP 1974

Figure	Ship	Date	Station #	Offshore Extent
1	DELTA SUD	March 8-9	2-4	50 nm
2	DELTA SUD	April 15-17	1-4	70 nm
3	DELTA SUD	May 21	49-51	70 nm
3	DELTA SUD	May 27-29	1-2	90 nm
4	DELTA SUD	June 28-29	16-18	90 nm
5	DELTA SUD	July 6-8	1-3	195 nm
5	DELTA NORTE	July 20-21	1-11	230 nm
6	MAYAQUEZ	August 17-18	1-3	85 nm
6	MAYAQUEZ	August 25-26	25-27	210 nm

TABLE 21.3

The offshore extent of the low surface salinity water discussed in Figures 21.3 and 5 apparently was controlled by the migration of 1 particular anticyclonic eddy. The southwestward migration of this eddy (as previously discussed in the eddy section) provided the mechanism for increasing the distance offshore of the lower salinity surface water.

In August (fig.21.6)the Mayaquez crossed through coastal water as low as 25 $^{\circ}/_{\circ\circ}$. These stations were located in deep water and the low salinity water had an offshore extent of 85 nm.

Again, in August (fig.21.6)the Mayaquez crossed through low salinity water less than 33 $^{\circ}/_{\circ\circ}$. The stations were located in deep water far removed from the shelf break and the low salinity water had an offshore extent of 210 nm.

The extent of the low salinity surface waters in the eastern Gulf of Mexico seemed to be controlled by the northward migrations of either eddies or the Loop Current itself. In some instances the low salinity surface waters were entrained into the eddy structure themselves (fig.21.3,4,5 and 6). In most cases where the low surface salinity water was entrained within the eddies the low salinity water appeared on only the northern side of the eddy. Peaks (ups and downs) in the surface plots (not shown) indicate the instances where low salinity water was transected, exited and then transected again. This indicated that the less saline surface waters were being entrained by the leading edges of the northward moving eddies.

The more saline oceanic waters were entraining the fresher coastal waters which developed into bands or rings of consecutively less saline-more saline-less saline water. The movements of the various eddies around the Gulf of Mexico would provide one mechansim for the extension tonguing and eventual mixing of the less saline coastal waters with the more saline oceanic waters.

Western Atlantic Transects

Specific features that were monitored in western North Atlantic by the program were the position of the Gulf Stream, variations in temperature and position of the bottom water cold cell on the continental shelf, position of the Shelf Water-Slope Water front, and eddies formed from the Gulf Stream. Where data were available and observations were close enough in time to permit comparison, correlations have been made with the National Environmental Satellite Service (NESS), Experimental Gulf Stream Analysis (N-69) charts and The Gulf Stream Monthly Summary which show the positions of the Gulf Stream and associated features.

Characteristics of the bottom water cold cell

In his discussion of temperature patterns in continental shelf water, Bigelow (1933) described a core of cold bottom water that extended from south of Long Island to the mouth of the Chesapeake and was evident throughout the summer months. According to Bigelow, this core was surrounded entirely by warmer water and could receive no replenishment during the summer; thus, he concluded it was formed in wintertime and then persisted throughout the year. Further descriptions of this cold cell have been given by Ketchum and Corwin (1966) and Whitcomb (1967). The data which are presented here show the formation, structure, and modification of this cell during 1974.

Nine observations of the cold cell were made by SOOP vessels in 1974. The cell characteristics at the time of observation are summarized in Table21.4. For purposes of discussion, the observations have been grouped into three separate geographic areas, chosen because they represent regularly-scheduled merchant ship cruise tracks. These tracks have been designated as the MORMAC transect (fig.21.7), SANTA CRUZ transect (fig.21.8) and HOTEL transect (fig.21.9). The MORMAC transect is the cruise track used by Moore-McCormack Line ships and closely follows a line between New York and Bermuda. The SANTA CRUZ transect extends from New York to Cape Hatteras, approximately along 74°W. The HOTEL transect is the cruise track used by Coast Guard cutters operating between Norfolk and OWS HOTEL (38°N, 71°W). In the following discussion, the seasonal characteristics and variations in the cold cell temperature and position along each transect have been summarized.

The temperature structure of water on the continental shelf during February (fig.21.10) should be considered, because the cold cell was formed from these waters and the minimum temperature that could be attained in the cell was dependent upon conditions during the winter months. At this time, cold water (7-12°C) extended from surface to bottom on the shelf and structure of the cell had not yet been established by stratification.

TABLE 21.4- Characteristics of the bottom water cold cell detected by SOOP vessels in 1974.

Transect	Ship Name	Date	Figure	Minimum Bottom Depth (m)	Maximum Bottom Depth (m)	Depth to Center (m)	Approximate Thickness at Center (m)	Temperature Range (°C)	Horizontal Extent (nm)
A	Santa Cruz	May 6	30	28	41	35	18	<8° - 9°	68 (126 km)
B	Mormac Argo	May 5-6	31	20	38	29	20	<9° -11°	65 (120 km)
C	Santa Cruz	Jun 11-12	33	32	49	45	23	<9° -13°	100 (185 km)
D	Mormac Rigel	Aug 14	35	40	55	50	23	<9° -13°	53 (98 km)
E	Santa Cruz	Sep 3-4	37	45	70	50	19	<9° -14°	90 (167 km)
F	USCGC Taney	Sep 29-30	38	40	55	50	15	<12° -15°	15 (28 km)
G	Export Defender	Oct 1	39	40	63	60	22	<12° -16°	29 (54 km)
H	Mormac Rigel	Oct 3	40	34	99	72	30	<11° -14°	110 (203 km)
I	Santa Cruz	Oct 9-10	41	45	70	50	20	<12° -14°	75 (139 km)

Along the MORMAC transect, the first evidence that the cell had formed was obtained on May 6 (fig.21.11). The characteristic shape of the cell had formed as shown by the outline of the 11°C isotherm in shelf waters. Within this "bubble-like" structure, temperatures ranged from less than 9° to 11°C. and the cell extended from a minimum bottom depth of 20 m to a maximum of 38 m. The horizontal extent was 65 nm (120 km) and the cell was approximately 20 m thick at the center. When next observed on August 14 (fig.21.12) temperatures in the cell ranged from less than 9° to 13°C and the bottom depth range of 40-55 m indicated that the cell was migrating into deeper water. The last observation was made on October 3 (fig.21.13). By this time, temperatures had warmed to 14°C in the outer edges of the cell and it had moved over the shelf break and bottom.. The depth range extended from 34-99 m. These changes in temperature and depth are summarized in Figure 21.7.

Along the Santa Cruz transect the earliest observation of the cold cell was made on May 6 (fig.21.14). Temperatures in the cell ranged from less than 8° to 9°C. The horizontal extent was 68 nm (126 km) and the cell ranged from 28-41 m in bottom depth with a thickness of about 18 m at the center. By June 11-12 (fig.21.15) the outer fringes of the cell had warmed to 13°C and water with temperatures from 10° - 13°C had begun to move seaward over the shelf break. The bottom depth range at this time was 32-49 m. Within the cell, two separate parcels of water (less than 9°C) were present between Stations 26-30. On September 3-4 (fig.21.16) temperatures in the cell were in the 9°-14°C range and part of the cell had moved over the shelf break and extended to a depth of 70 m. The tongue-like shape of the 13° and 14°C isotherms showed the initial stages of a process called "calving" by Cresswell (1967) whereby a parcel of water separates from the parent mass and moves seaward. During October 9-10 (fig.21.17) the "calving" process was detected in an advanced stage. A mass of water with temperatures ranging from 12-14°C had separated from the cell on the shelf and was moving seaward over the shelf break. At this time, the cell extended to a maximum bottom depth of 70 m. These changes in temperature and depth are summarized in Figure 21.8.

Only two observations of the cold cell were made along the HOTEL transect, and these were closely spaced in time - September 29-30 (fig. 21.18 and October 1 (fig.21.19). Figure 21.18 showed temperatures ranging from less than 12 ° to 15°C in the cell over a bottom depth range of 40-55 m. The horizontal extent was only 15 nm (28 km). Slightly further south, the temperatures ranged from less than 12° to 16° over a bottom depth range of 40-63 m. Here the horizontal extent was 29 nm (54 km). The changes in temperature and depth are summarized in Figure 21.9.

Gulf Stream

Considerable attention has been focused on fluctuations in the position of the Gulf Stream. In addition to shipboard observations of temperature and salinity, satellite and aircraft observations of surface temperature are being used to differentiate between water masses. Because the SOOP transects intersect with the Gulf Stream at discrete points with considerable spatial and temporal variations between transects, complete coverage of the Gulf Stream and associated features is impossible. However, when correlated with the satellite observations the transect data provide a source of ground truth for the remote sensors, as well as providing additional information for investigators involved in study of the Gulf Stream system and other water masses.

During 1974, SOOP transects crossed the Gulf Stream 12 times. These crossings are summarized in Figures 21.20, 21.21, 21.22, and 21.23 and Table 21.5. Gulf Stream crossings were identified by the strong horizontal gradients shown on vertical temperature sections and positions of the North Wall were determined by using the 15°C isotherm at 200 m (Worthington, 1964).

Both *The Gulf Stream Monthly Summary* and the NESS Experimental Gulf Stream Analysis (N-69) charts provide information about fluctuations in the Gulf Stream position. The information provided in these publications gives more complete and synoptic coverage over the entire Gulf Stream system than is possible through SOOP transects. However, since the N-69 charts are derived solely from remote sensing of sea surface temperatures and *The Gulf Stream Monthly Summary* is at least partially dependent upon these data, the patterns shown by these publications may not be as accurate as those portrayed from subsurface temperature data. The information collected by the SOOP affords an excellent source with which these data can be verified.

Table 21.6 shows the Gulf Stream positions as determined from each source. In each case, the distance has been measured with dividers along identical bearing lines and this distance converted to nautical miles. Several sources of error were apparent. The inconsistent quality of reproduced N-69 charts and the distortion introduced by photocopying lead to some uncertainty in measurements, though this varied between sources. In addition, some interpolation was necessary to locate positions between stations on vertical sections. Interpolation was also necessary to determine positions during mid-month from *The Gulf Stream Monthly Summary* because positions were given only at the beginning and end of the month. An estimate of these errors accompanies each measurement.

TABLE 21.5 - Gulf Stream Crossings by NMFS/MARAD Ships of Opportunity in 1974.

Figure	Ship Name	Date	Position
31	Mormac Argo	May 5-6	38°30'N, 71°12'W
32	Santa Cruz	May 17-18	31°48'N, 79°06'W
33	Santa Cruz	June 11-12	38°12'N, 73°57'W
34	Santa Cruz	July 28	34°48'N, 75°24'W
35	Mormac Rigel	Aug 14	37°42'N, 70°48'W
37	Santa Cruz	Sep 3-4	35°30'N, 75°00'W
39	Export Defender	Oct 1	36°42'N, 72°18'W
40	Mormac Rigel	Oct 3	37°30'N, 71°00'W
41	Santa Cruz	Oct 9-10	36°12'N, 74°12'W
42	Santa Cruz	Oct 19	35°00'N, 75°00'W
44	Export Defender	Nov 27-28	36°00'N, 74°00'W
45	Santa Cruz	Dec 7-8	36°00'N, 75°18'W

TABLE 21.6 - Comparison of Gulf stream position as located by SOOP, NESS N-69 charts and Gulf Stream Monthly Summary.

SOOP			N-69 Charts		Gulf Stream	
Figure/date	Bearing Line	Distance	Date/Bearing Line	Distance	Date/Bearing Line	Distance
31 May 5-6, 1974	Sandy Hook-130°	171±12 nm (317±22 km)	May 4-7, 1974 Sandy Hook-130°	155±35 nm (287±65 km)	May Sandy Hook-130°	235±10 nm (435±19 km)
32 May 17-18, 1974	Charleston,S.C. 147°	87±10 nm (161±19 km)	Cloud Cover	--	May Charleston, S.C. 147°	84±12 nm (156±22 km)
33 June 11-12, 1974	Cape Charles 124°	118±15 nm (219±28 km)	June 6-10, 1974 Cape Charles-124°	90±15 nm (167±28 km)	June Cape Charles-124°	100±18 nm (185±33 km)
34 July 28, 1974	Cape Charles 170°	140±25 nm (259±46 km)	Cloud Cover	--	July Cape Charles-170°	144±10 nm (267±19 km)
35 August 14, 1974	Sandy Hook 137°	222±15 nm (411±28 km)	August 15-20, 1974 Sandy Hook-137°	225±10 nm (417±19 km)	August Sandy Hook-137°	215±24 nm (398±44 km)
37 September 3-4,1974	Cape Charles 161°	132±15 nm (245±28 km)	September 4-10, 1974 Cape Charles-161°	120±10 nm (222±19 km)	September Cape Charles-161°	115±10 nm (213±19 km)

TABLE 21.6 (Cont'd)

SOOP			N-69 Charts		Gulf Stream	
Figure/date	Bearing Line	Distance	Date/Bearing Line	Distance	Date/Bearing Line	Distance
39 October 1, 1974	Cape Charles 95°	174± 6 nm (322±11 km)	September 27 - October 1, 1974 Cape Charles-95°	165±15 nm (306±28 km)	October Cape Charles-95°	150±10 nm (278±19 km)
40 October 3, 1974	Sandy Hook 137°	225± 6 nm (417±11 km)	October 4-6, 1974 Sandy Hook-137°	230±20 nm (426±37 km)	October Sandy Hook-137°	210±10 nm (389±19 km)
41 October 9-10, 1974	Cape Charles 128°	120±20 nm (222±37 km)	October 11, 1974 Cape Charles-128°	95±10 nm (176±19 km)	October Cape Charles-128°	120±10 nm (222±19 km)
42 October 19, 1974	Cape Charles 161°	120±10 nm (222±19 km)	October 18-22, 1974 Cape Charles-161°	120±15 nm (222±28 km)	October Cape Charles-161°	125±12 nm (232±22 km)
44 November 27-28, 1974	Cape Charles-140°	102± 6 nm (189±11 km)	November 21-24, 1974 Cape Charles-140°	91±15 nm (169±28 km)	November Cape Charles-140°	100±10 nm (185±19 km)
45 December 7-8, 1974	Cape Charles 163°	100±50 nm (185±93 km)	December 5-10, 1974 Cape Charles-163°	135±12 nm (250±22 km)	December Cape Charles-163°	121±10 nm (224±19 km)

Within the estimated range measurement errors, the sources agreed closely on the position of the Gulf Stream North Wall. Only in May was there a significant discrepancy in the measurements. The distance of the North Wall measured from The Gulf Stream Monthly Summary was about 40 nm greater than the distance determined from SOOP data on the N-69 charts. This probably was due to the fact that The Gulf Stream Monthly Summary only provided information at the beginning and end of the month and thus the Gulf Stream position determined from this source during mid-May was highly conjectural.

Eddies

From analysis of the vertical sections contained in this report, four Gulf Stream eddies were detected during 1974 (see Table 21.7 and fig. 21.24). Eddy #1 (fig. 21.25) was crossed by Santa Cruz on May 5-6 and was centered at Station 7 (32°00'N, 75°00'W). The sloping of the isotherms indicated an asymetrical cold core eddy, possibly in the act of becoming entrained in the Gulf Stream. The Gulf Stream Monthly Summary (April) showed an eddy centered at 33°00'N, 74°00'W on 30 March 1974. Since the eddy was not shown in the May issue, it may have become entrained during the interval. This eddy was not shown on the N-69 charts.

On May 5-6 (fig. 21.11) Mormac Argo crossed a cyclonic, cold core eddy (Eddy #2) that was centered around Station 8 (36°00'N, 68°00'W). The structure of the eddy was evident to a depth of about 600 m and the width at the surface was approximately 145 nm (269 km). The May issue of The Gulf Stream Monthly Summary showed a cyclonic eddy with a width of about 80 nm (148 km) centered at a position of 36°30'N, 68°00'W, which corresponded closely to the position of Eddy #2. No correlation could be made with the NESS N-69 charts of 4-7 May 1974 because there was heavy cloud cover in the study area. However, the 14 May 1974 N-69 charts showed a cold water intrusion in this area. Comparison of the XBT traces with the sample traces shown in The Gulf Stream Monthly Summary revealed reasonable similarity; it was concluded that Eddy #2 was the same eddy depicted in the May summary.

Figure 21.11 also showed another unusual feature. An unusually strong thermal gradient (surface temperatures changed from 23°-20°C over a distance of 15 nm or 28 km) was present between Stations 3 and 4. Similar fronts in the Sargasso Sea have been described by Katz (1969), Voorhis (1969), and Voorhis and Hersey (1964).

Eddy #3 (fig. 21.26) was located by USCGC Ingham on 20 October 1974. This anticyclonic warm core eddy was located around 37°N, 74°W. An intrusion of warm water shown on the 23-28 October and 31 October-3 November N-69 charts, could be a result of this warm eddy moving into this region. However, no eddy was shown at this location in the October or November issues of The Gulf Stream Monthly Summary.

TABLE 21.7 - Gulf Stream Eddies Surveyed by SOOP Vessels in 1974

Eddy Number	Figure/ Date	Location of Center	Approximate Surface Diameter	Maximum Observed Depth	Direction of Rotation
1	29 May 5	32°N, 75°W	165 nm (306 km)	650 m	Cyclonic
2	31 May 5-6	36°N, 68°W	145 nm (269 km)	500 m	Cyclonic
3	43 Oct 20	37°N, 74°W	90 nm (167 km)	450 m	Anticyclonic
4	45 Dec 7-8	32°N, 73°30'W	150 nm (278 km)	660 m	Cyclonic

Eddy #4 (fig. 21.27), a cold core, cyclonic eddy, was crossed by Santa Cruz on 7-8 December 1974. The maximum depth observed by XBT was 660 m, while the eddy center was located around 32°00'N, 73°30'W (station 14). This eddy was apparently the same one that was monitored with neutrally buoyant floats by the U.S. Naval Oceanographic Office and surveyed on 11 December 1974 by P.L Richardson aboard R/V Trident (Gemill, 1974; Anonymous, 1975; Gemill and Cheney, 1975). Surface heating had destroyed any surface signature of the eddy and only subsurface data proved its existence.

Shelf Water-Slope Water Front

SOOP transects crossed the Shelf Water-Slope Water front five times during 1974. Determinations of frontal crossings were made primarily on the basis of subsurface temperature gradients shown on the vertical sections with additional supporting evidence being drawn from surface temperature and salinity gradients. A summary of these crossings is given in Table 21.8 and in Figures 21.20, 21.21, 21.22, and 21.23.

In order to provide a means of verification of the position of the front as determined from SOOP sections, comparisons have been made with NESS N-69 charts. After the position of the front was determined on the SOOP sections, a bearing line was established to a nearby landmark. The distance in nautical miles was measured with a pair of dividers and an estimate of error was made. The position of the front was then measured along the same bearing line on the N-69 charts. These comparisons are shown in Table 21.9. Within the estimated range of measurement error, the positions determined from the two sources agreed closely, suggesting that the methods currently used are reliable indicators of the frontal position.

TABLE 21.8- Shelf Water-Slope Water Front Crossings by NMFS/MARAD Ships of Opportunity in 1974

Figure	Ship Name	Date	Frontal Position
33	Santa Cruz	June 11-12	38°N, 71°48'W
35	Mormac Rigel	August 14	39°42'N, 73°W
37	Santa Cruz	September 3-4	38°N, 74°W
38	USCGC Taney	September 29-30	37°N, 75°W
41	Santa Cruz	October 9-10	38°18'N, 73°54'W

TABLE 21.9 - Comparison of positions of Shelf Water - Slope Water Front as detected by the NMFS Ship of Opportunity Program and the NESS Experimental Gulf Stream Analysis (N-69) charts.

	SOOP			N-69		
Figure	Date	Bearing Line	Distance	Date	Bearing Line	Distance
33	June 11-12	Cape Charles-53°	132 ± 15 nm (245 ± 28 km)	June 13-18	Cape Charles-53°	156 ± 18 nm (289 ± 33 km)
35	August 14	Sandy Hook-141°	72 ± 15 nm (133 ± 28 km)	August 12	Sandy Hook-141°	90 ± 10 nm (167 ± 19 km)
37	September 3-4	Cape Charles-53°	108 ± 12 nm (200 ± 22 km)	Cloud Cover in Study Area-no Measurement possible		
38	September 29-30	Cape Charles-86°	66 ± 10 nm (122 ± 19 km)	September 27 - October 1	Cape Charles-86°	66 ± 12 nm (122 ± 22 km)
41	October 9-10	Cape Charles-53°	132 ± 20 nm (245 ± 37 km)	October 11	Cape Charles-53°	102 ± 10 nm (189 ± 19 km)

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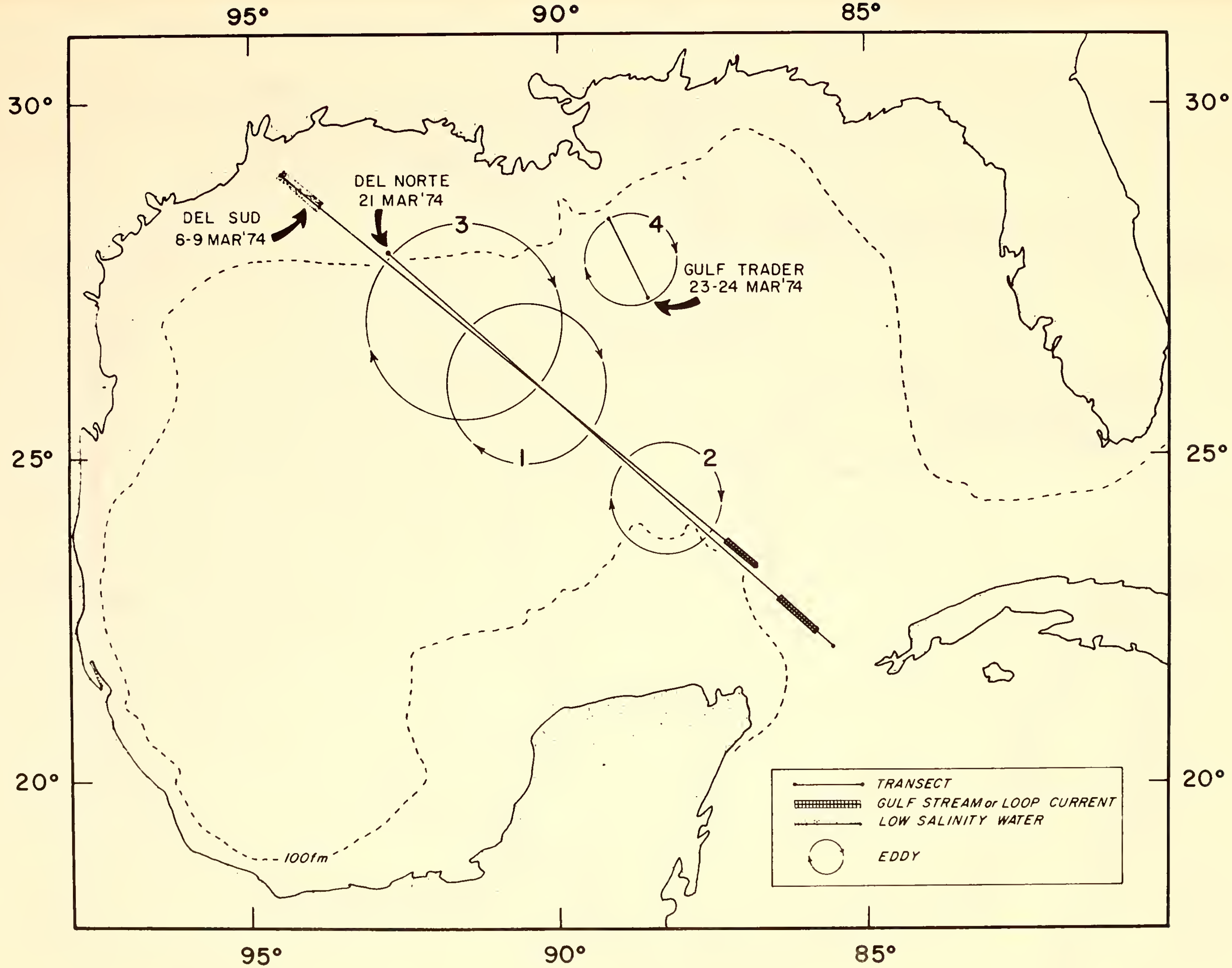


Figure 21.1 Composite plot of Gulf of Mexico eddies for March, 1974.

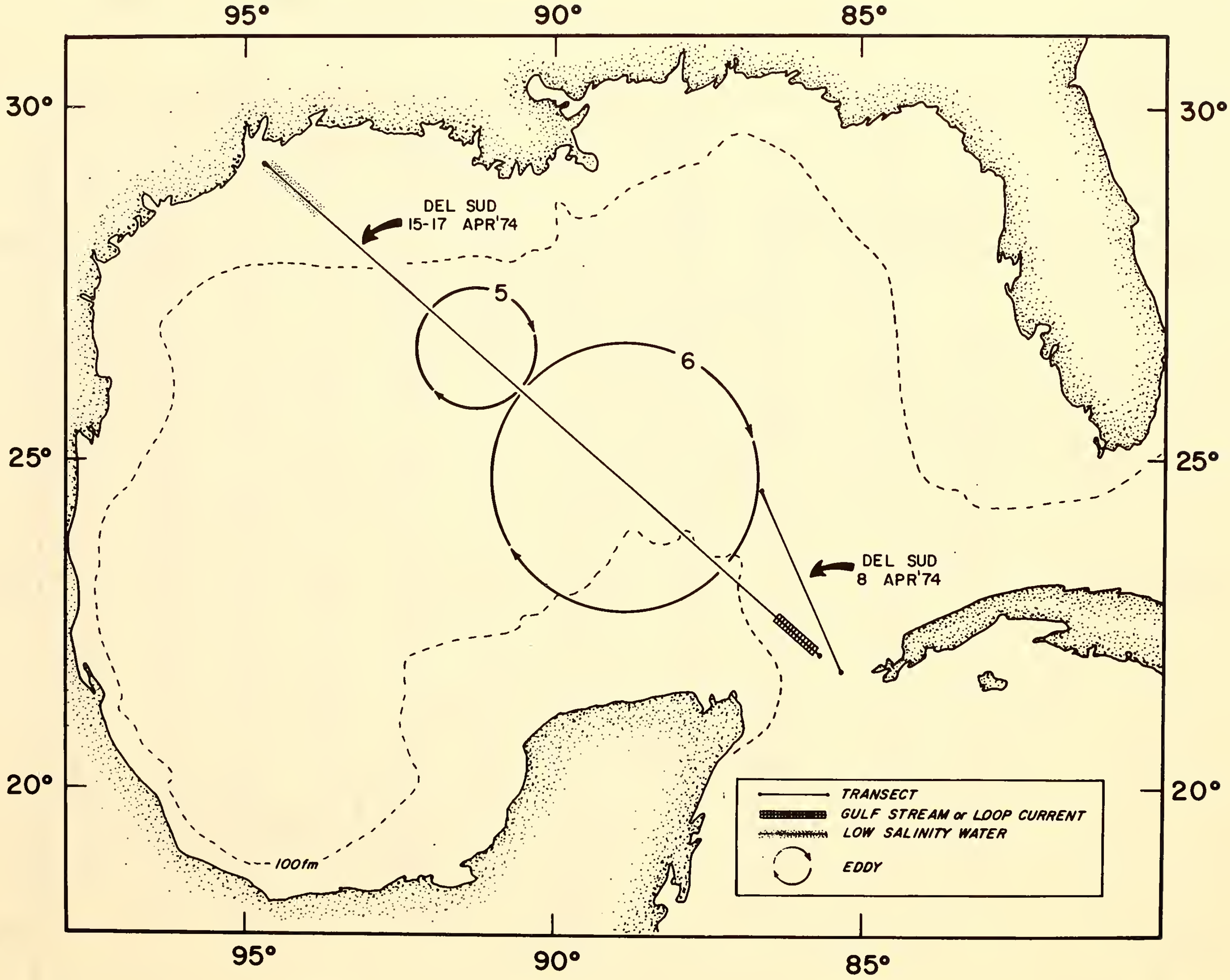


Figure 21.2 Composite plot of Gulf of Mexico eddies for April, 1974.

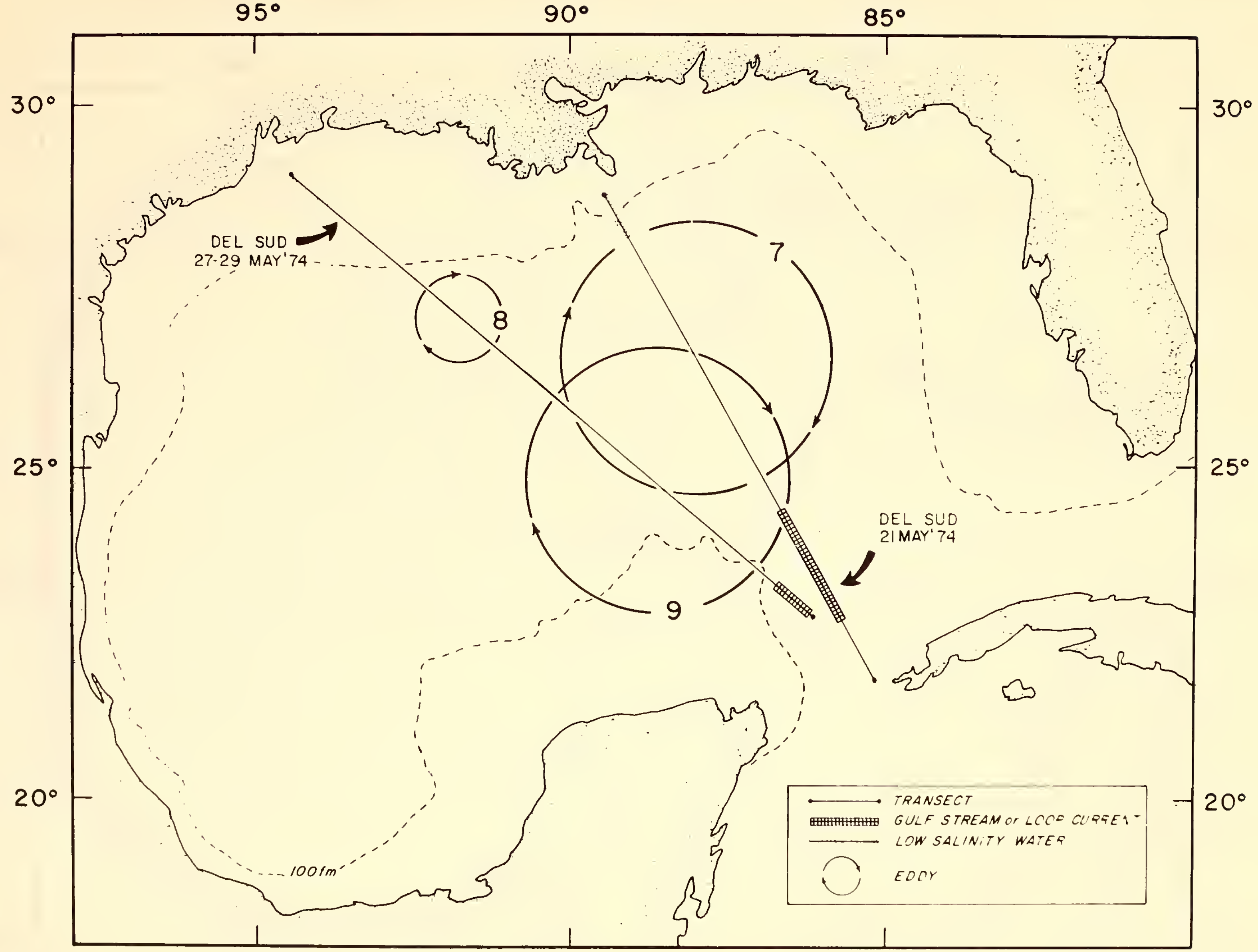


Figure 21.3 Composite plot of Gulf of Mexico eddies for May, 1974.

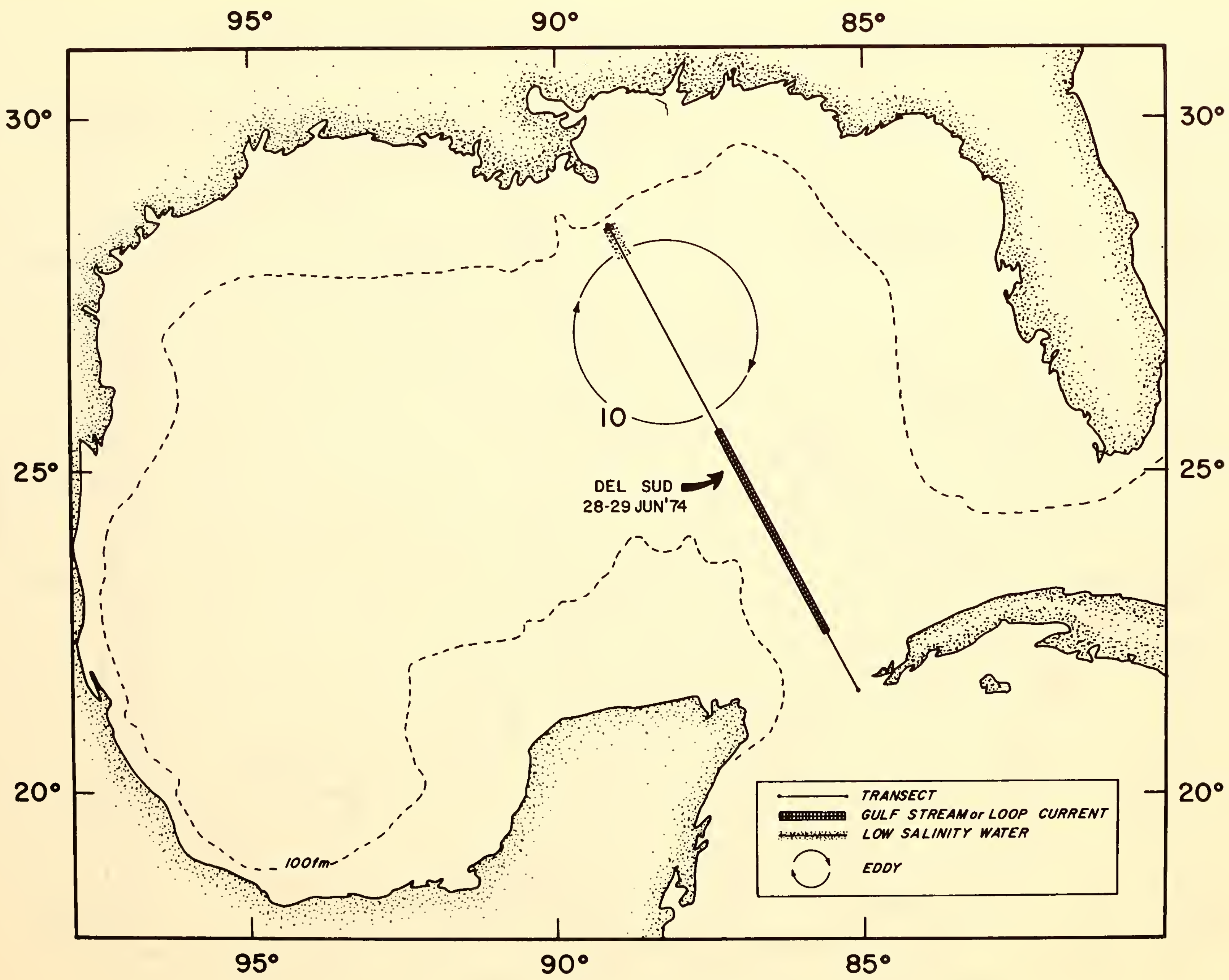


Figure 21.4 Composite plot of Gulf of Mexico eddies for June, 1974.

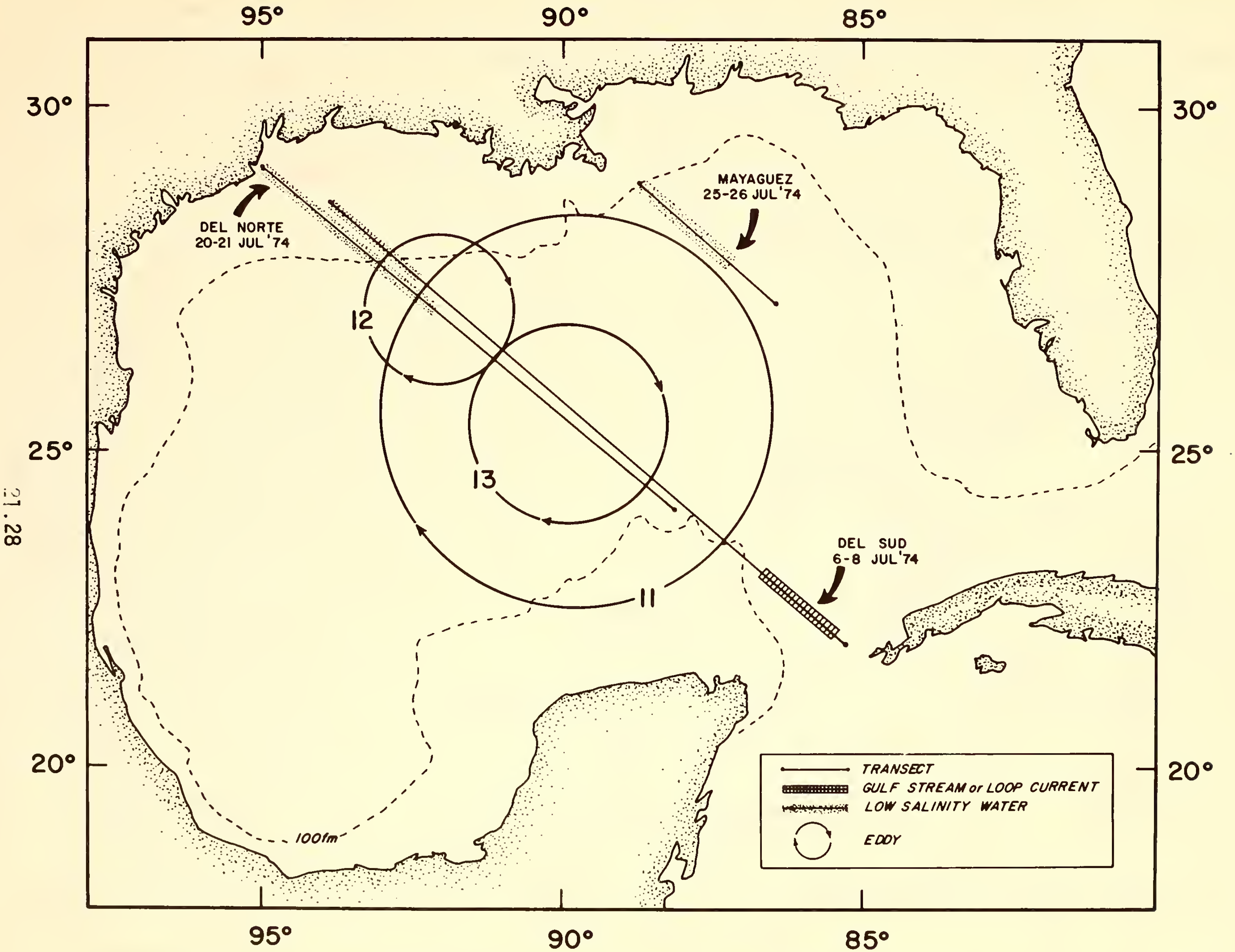


Figure 21.5 Composite plot of Gulf of Mexico eddies for July, 1974.

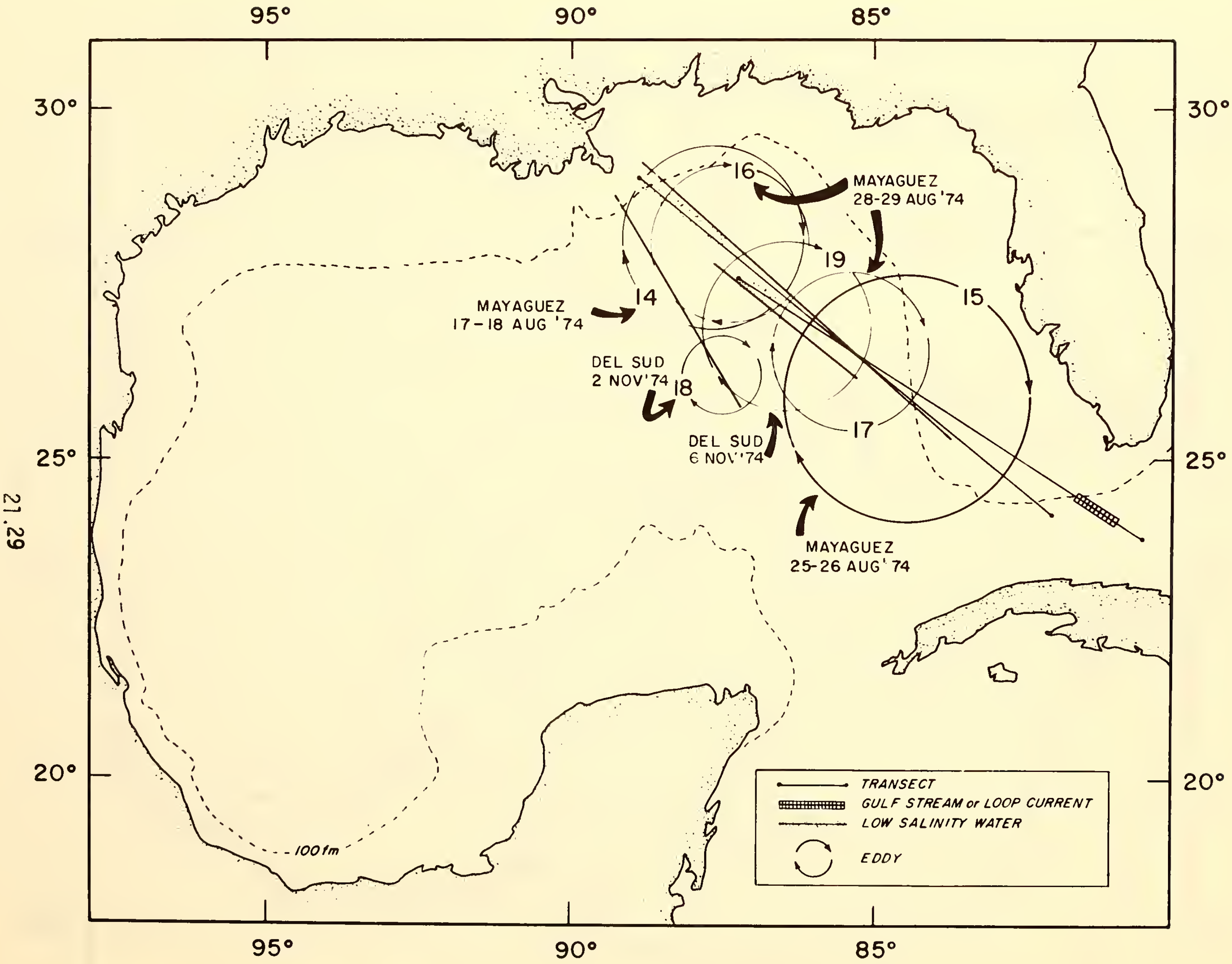


Figure 21.6 Composite plot of Gulf of Mexico eddies for August-November, 1974.

VARIATIONS IN COLD CELL TEMPERATURE AND DEPTH ALONG MORMAC TRANSECT

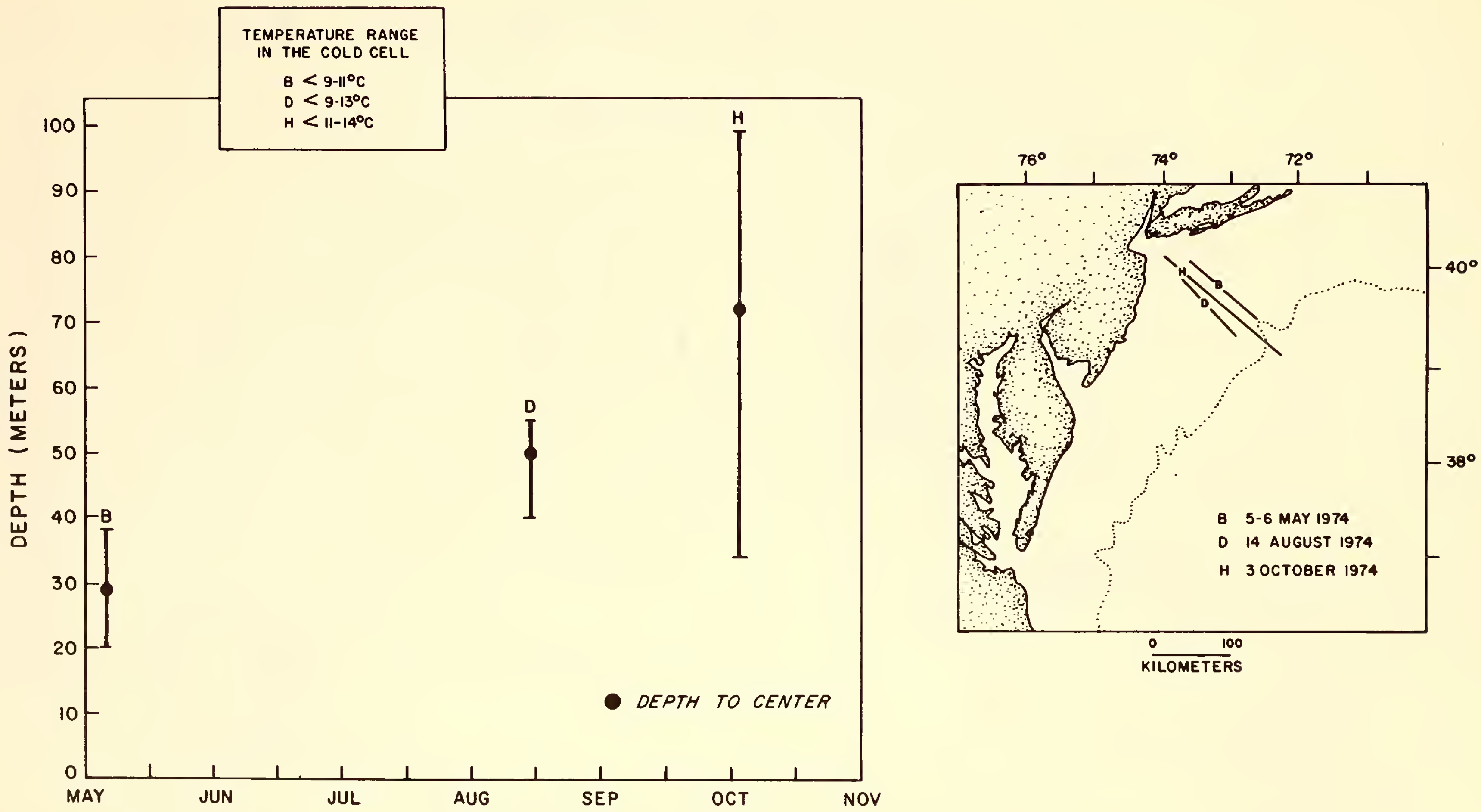
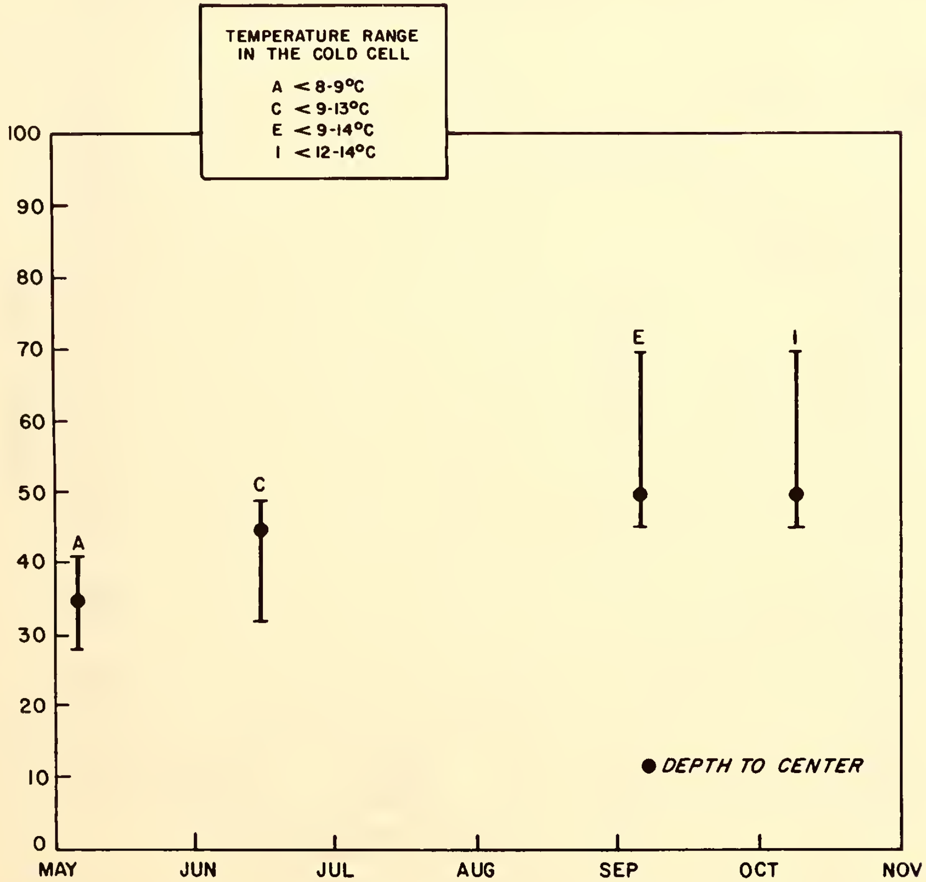


Figure 21.7 Variations in cold cell temperature and depth along MORMAC transect.

VARIATIONS IN COLD CELL TEMPERATURE AND DEPTH ALONG SANTA CRUZ TRANSECT



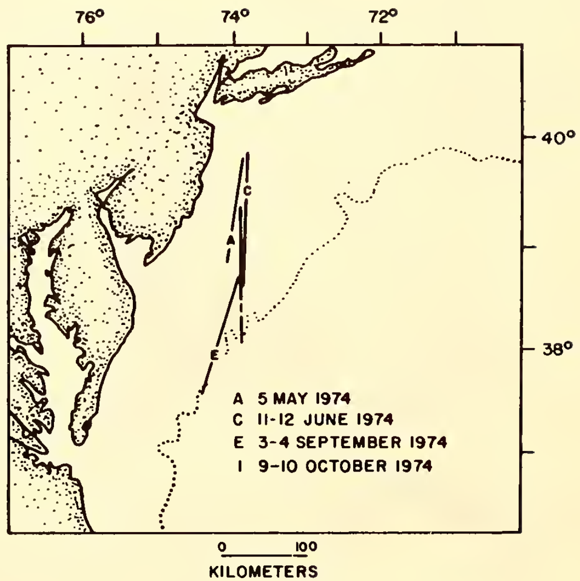


Figure 21.8 Variations in cold cell temperature and depth along SANTA CRUZ transect.

VARIATIONS IN COLD CELL TEMPERATURE AND DEPTH ALONG HOTEL TRANSECT

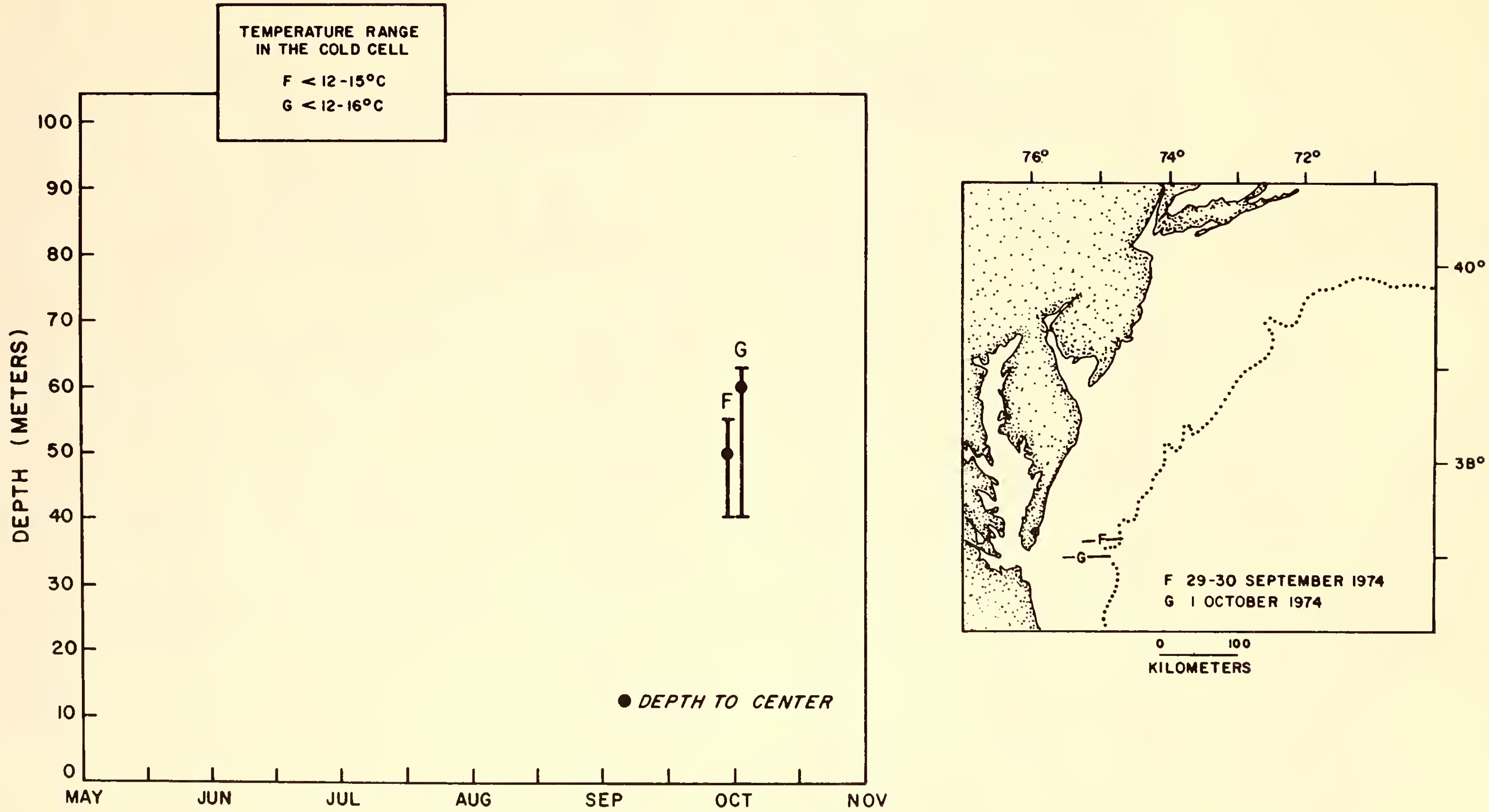


Figure 21.9 Variations in cold cell temperature and depth along HOTEL transect.

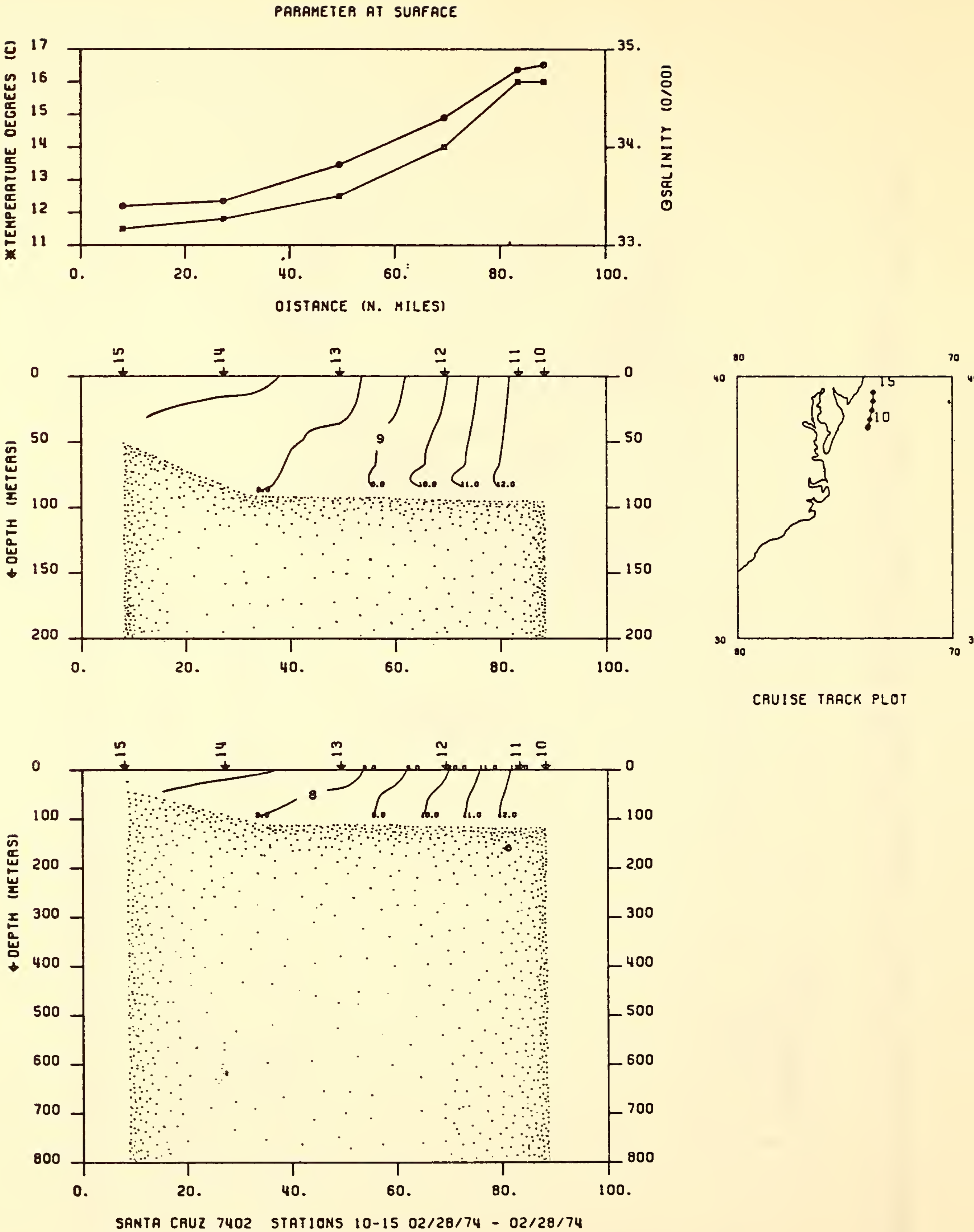


Figure 21.10. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

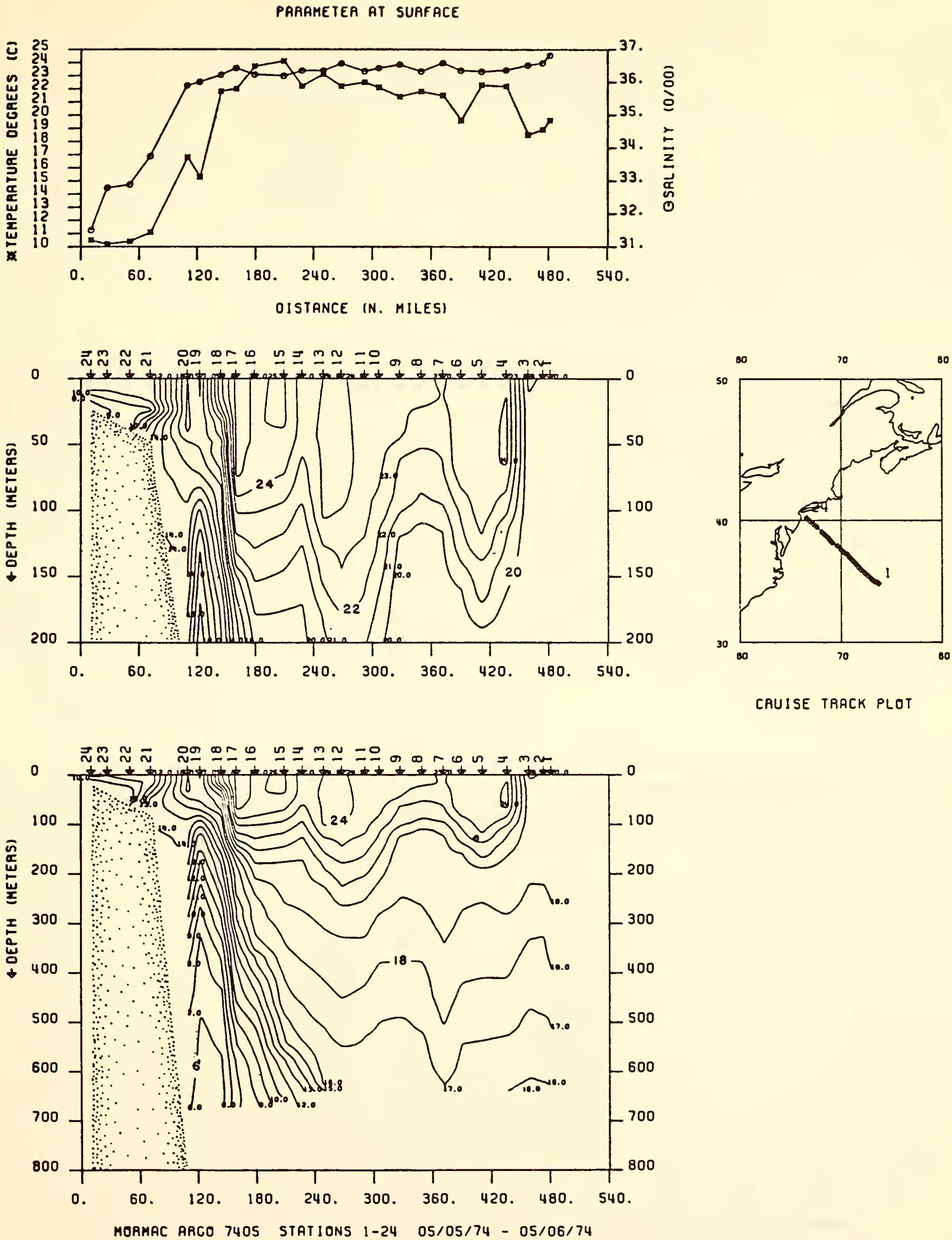


Figure 21.11. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

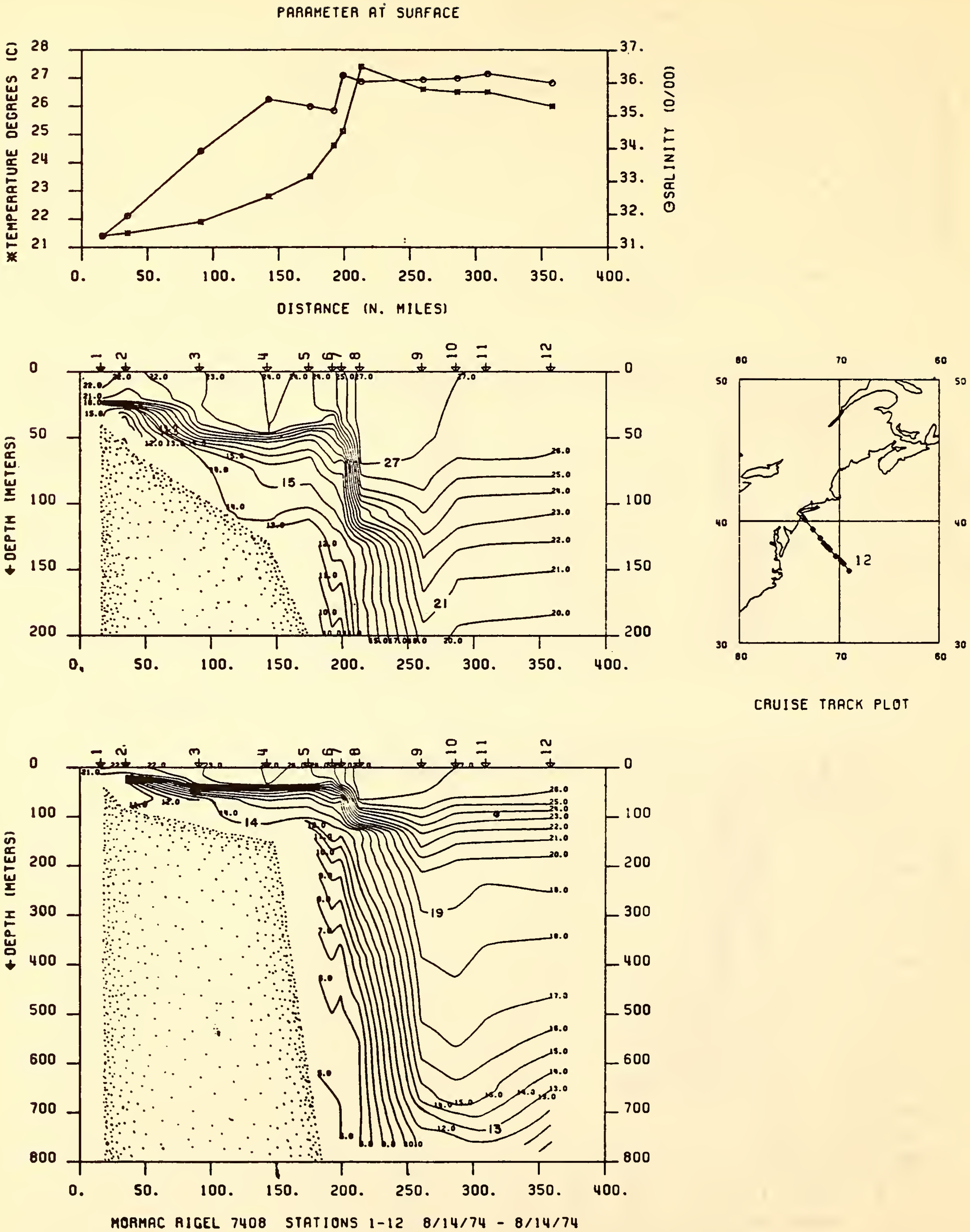


Figure 21.12 . Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

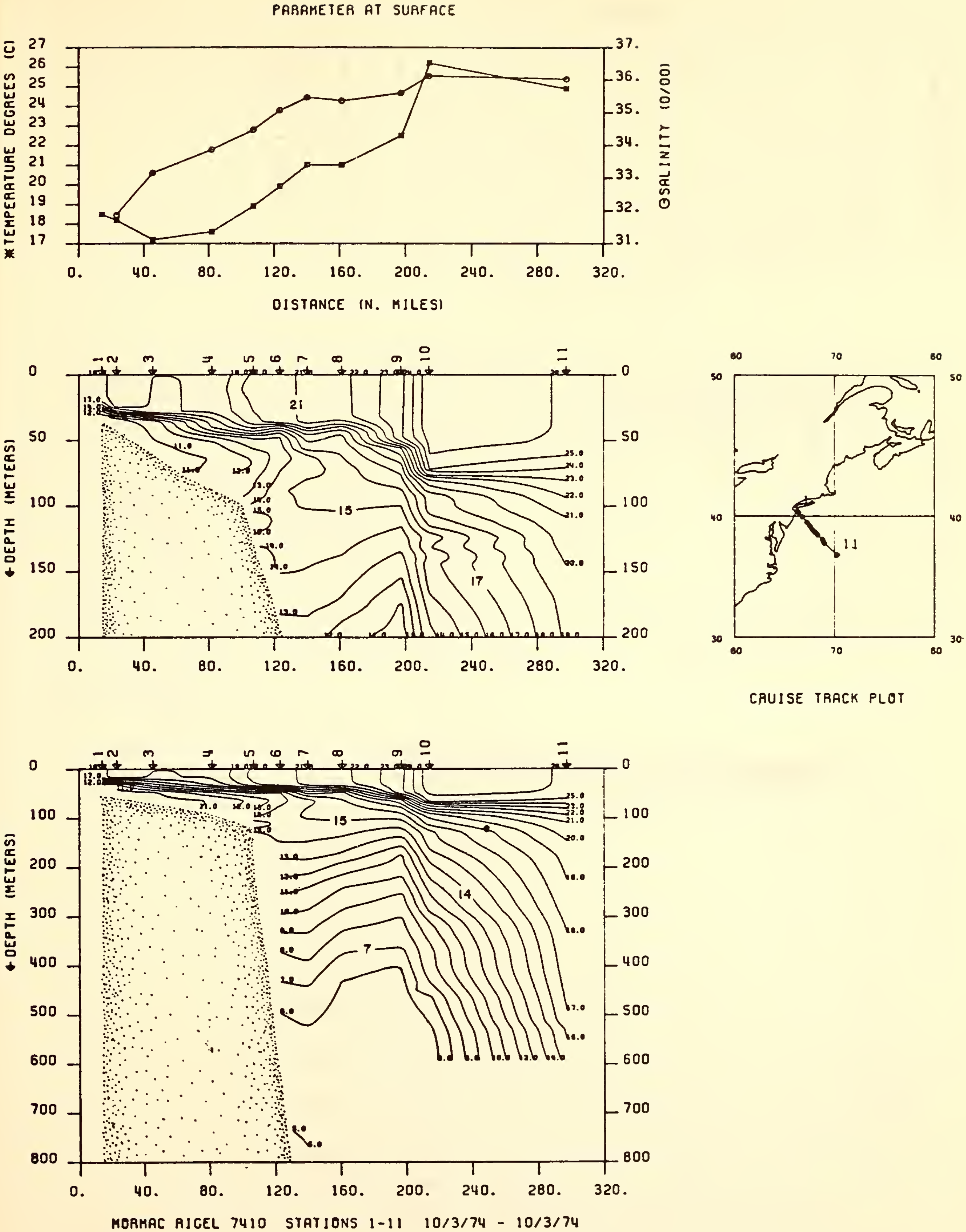


Figure 21.13. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

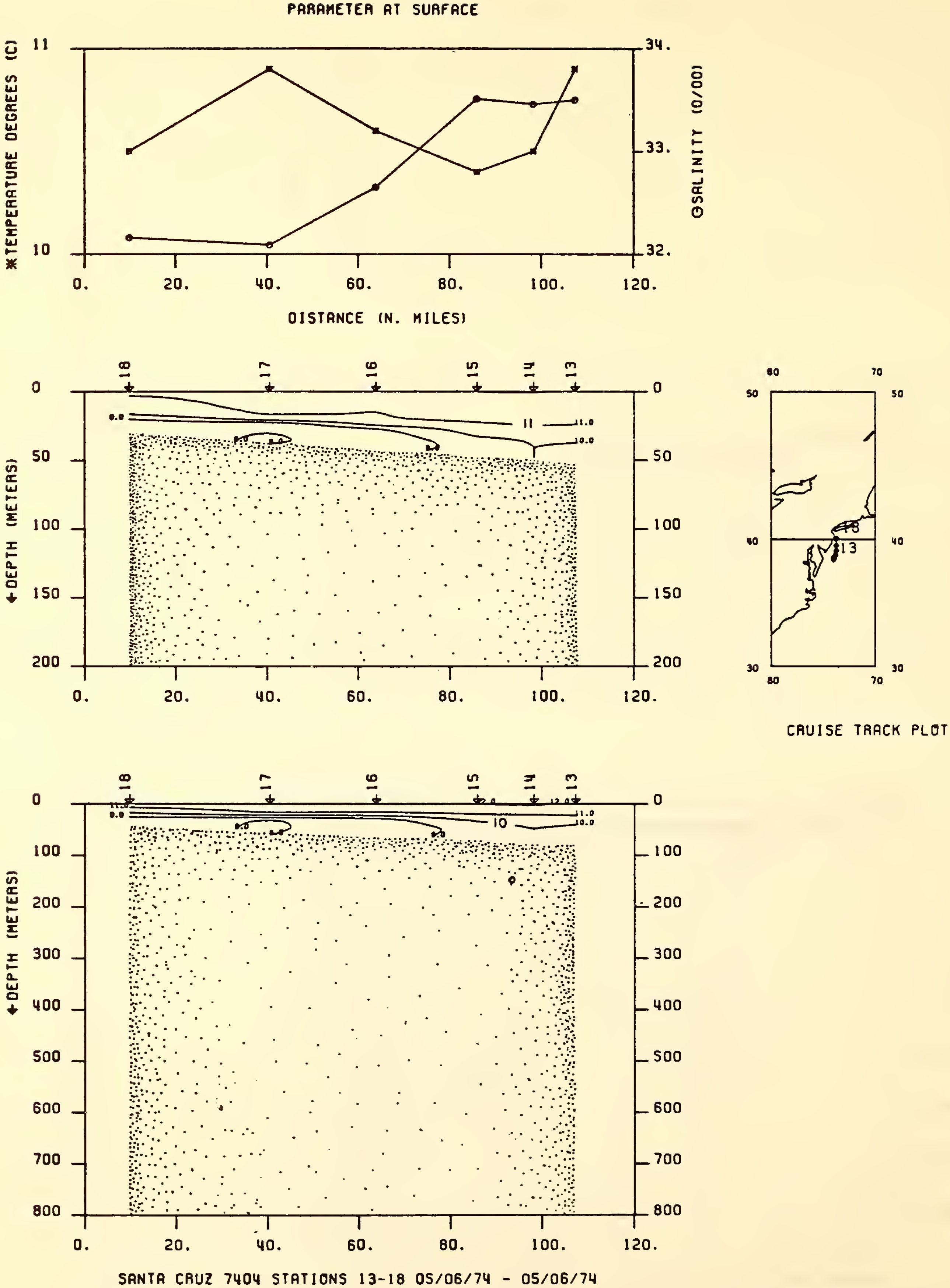


Figure 21.14. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

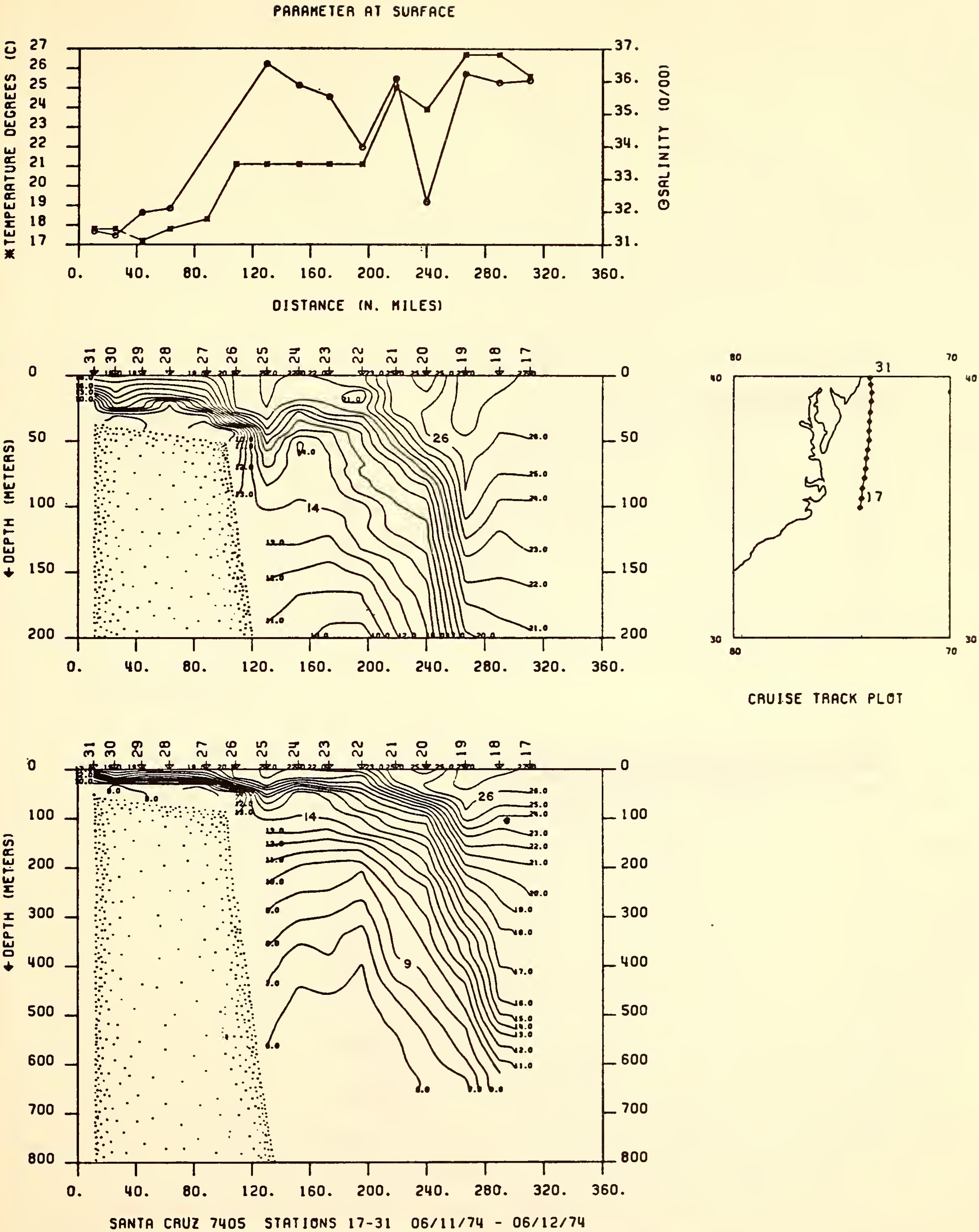
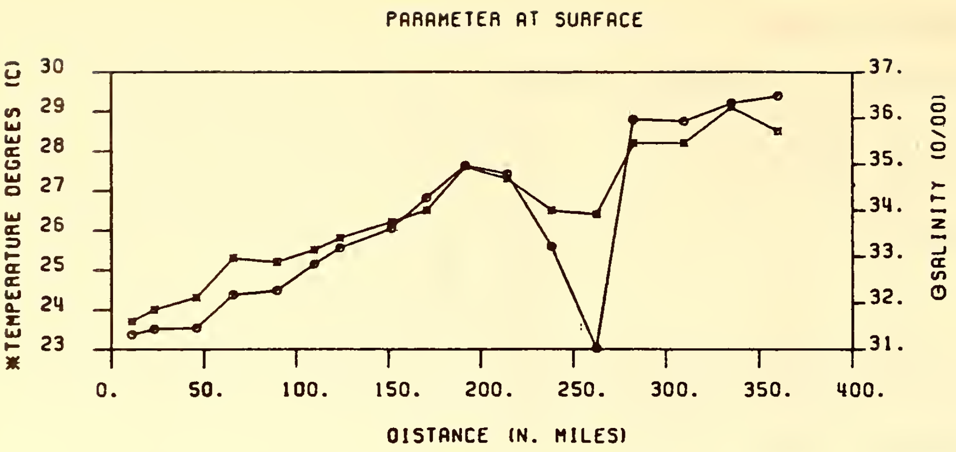
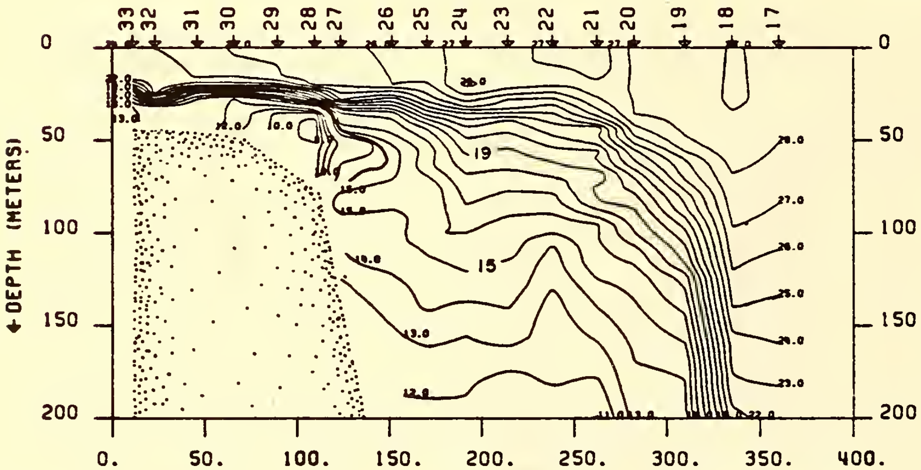


Figure 21.15. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.





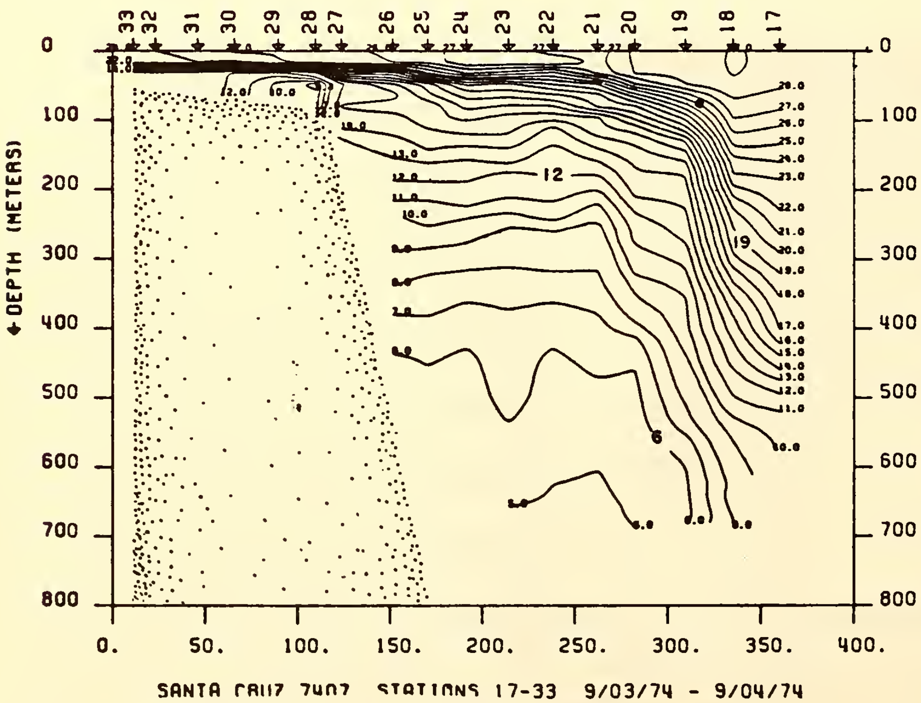


Figure 21.1 6. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

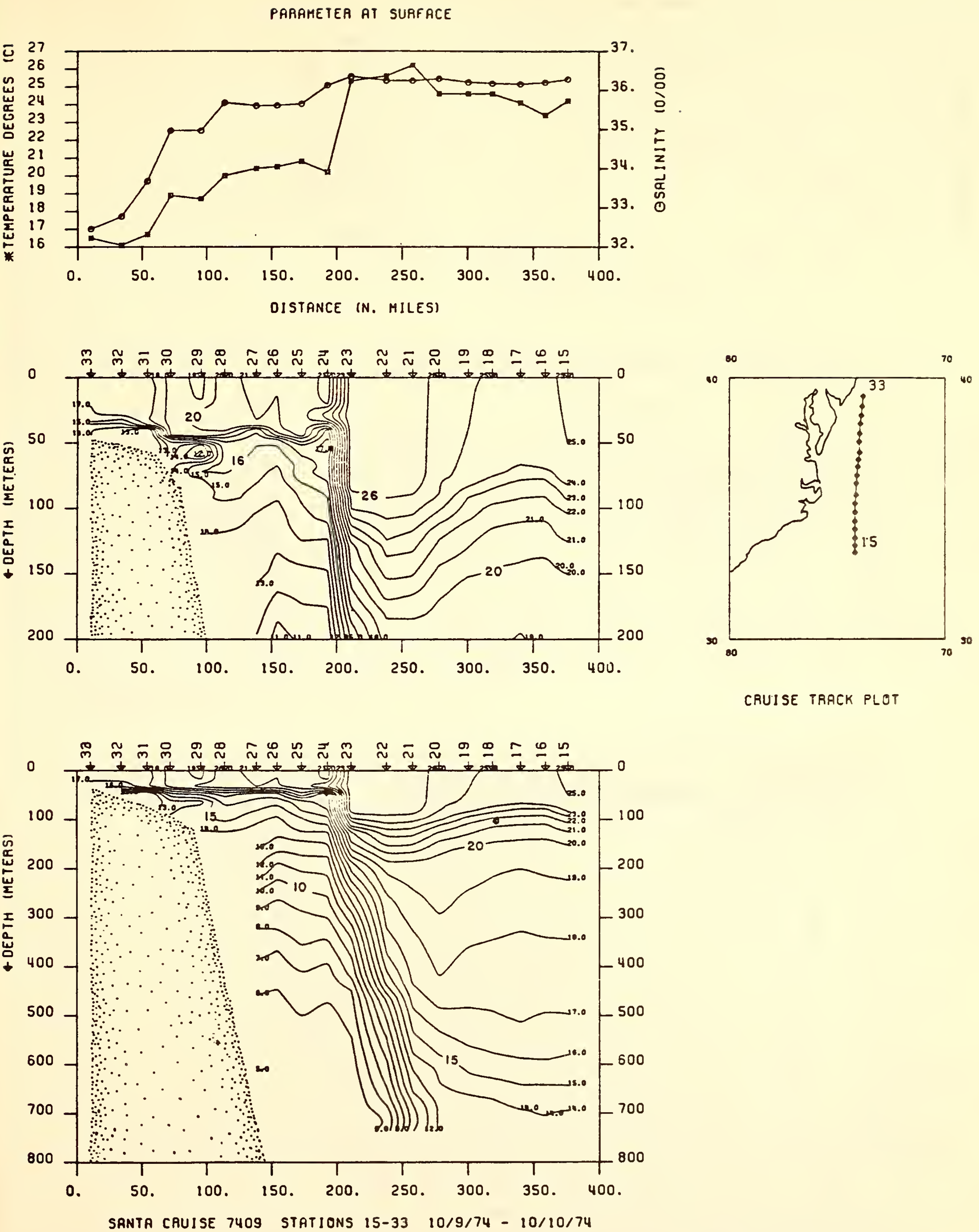


Figure 21.1 7 Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

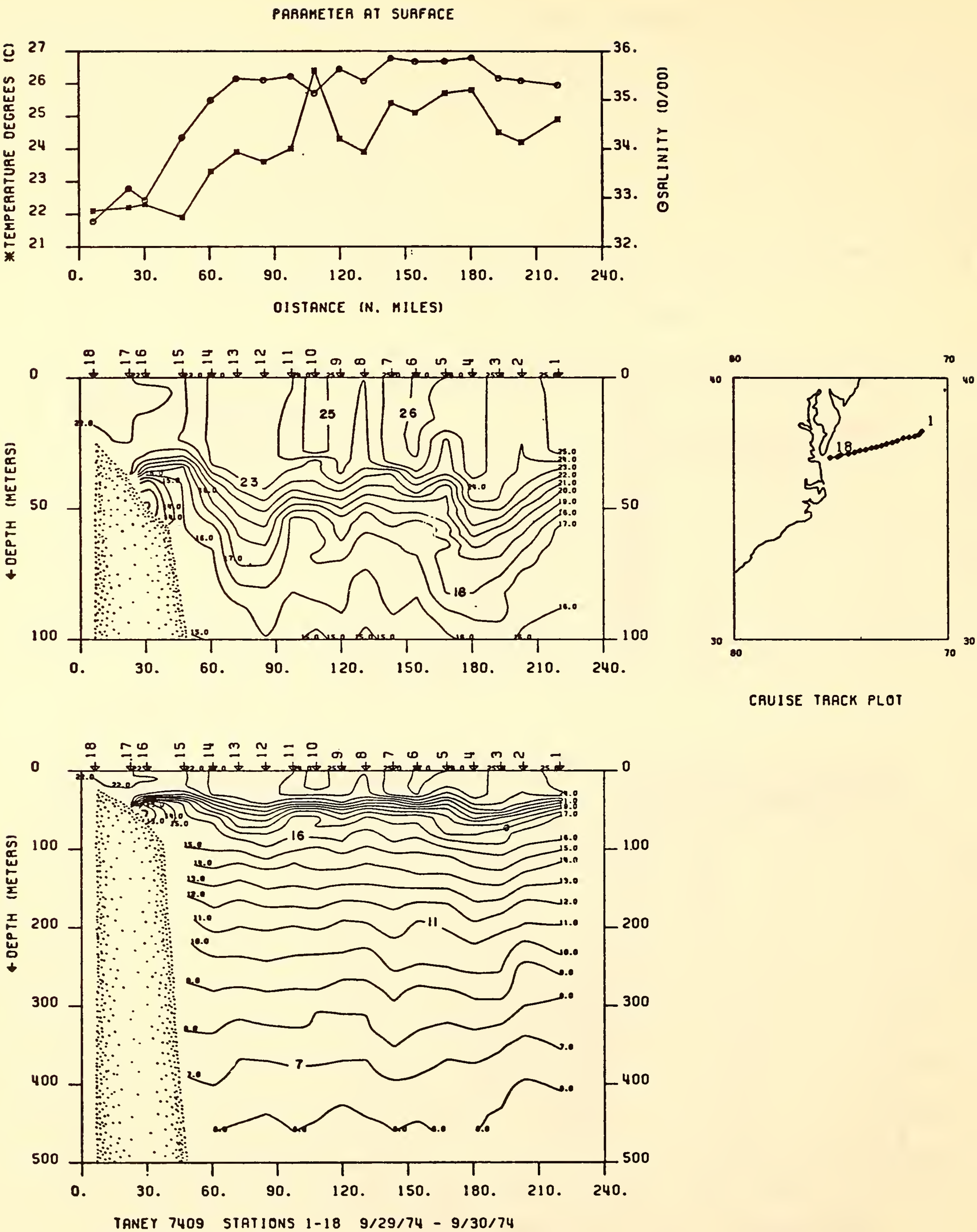


Figure 21.18. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

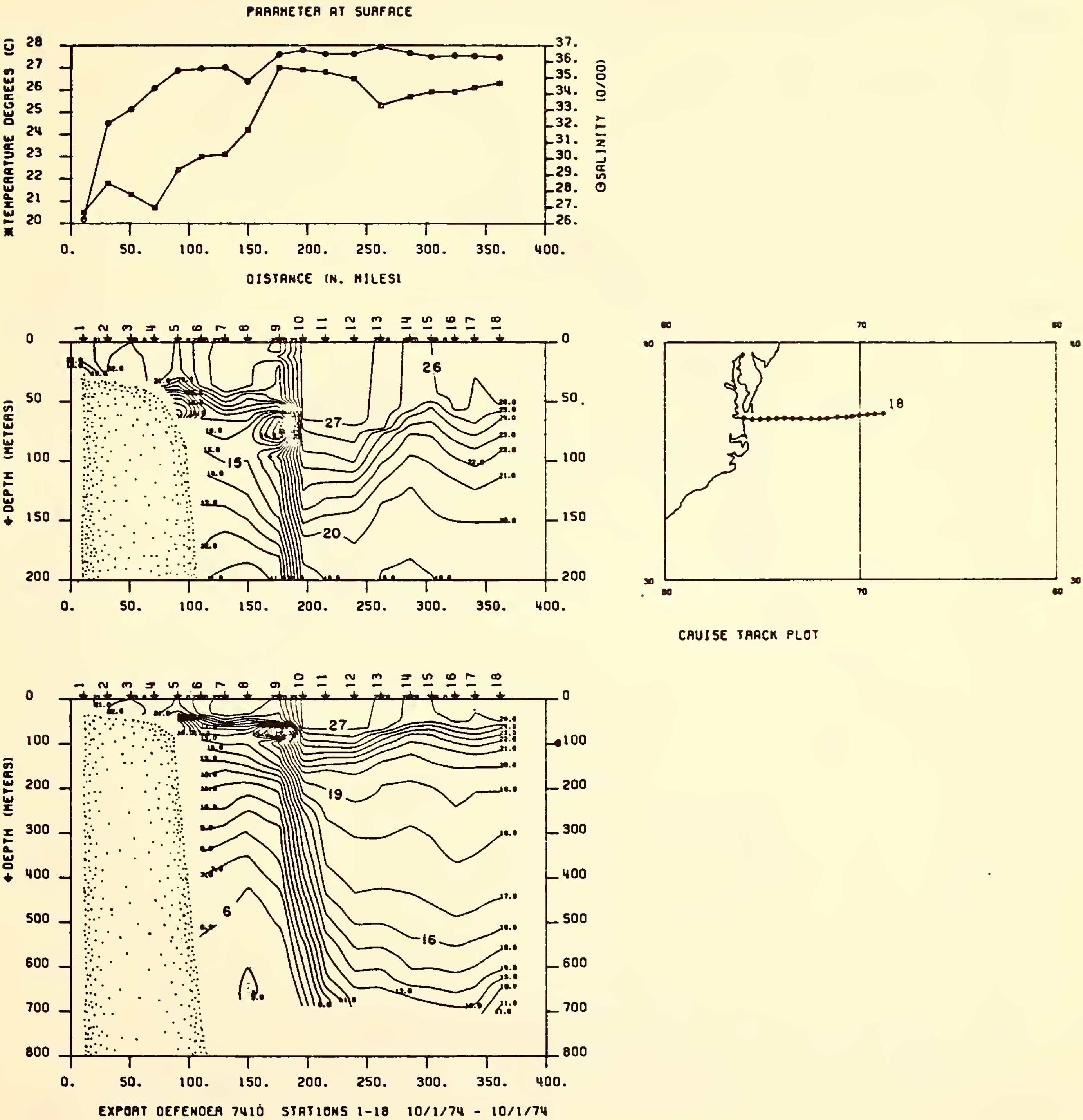


Figure 21.1 9. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

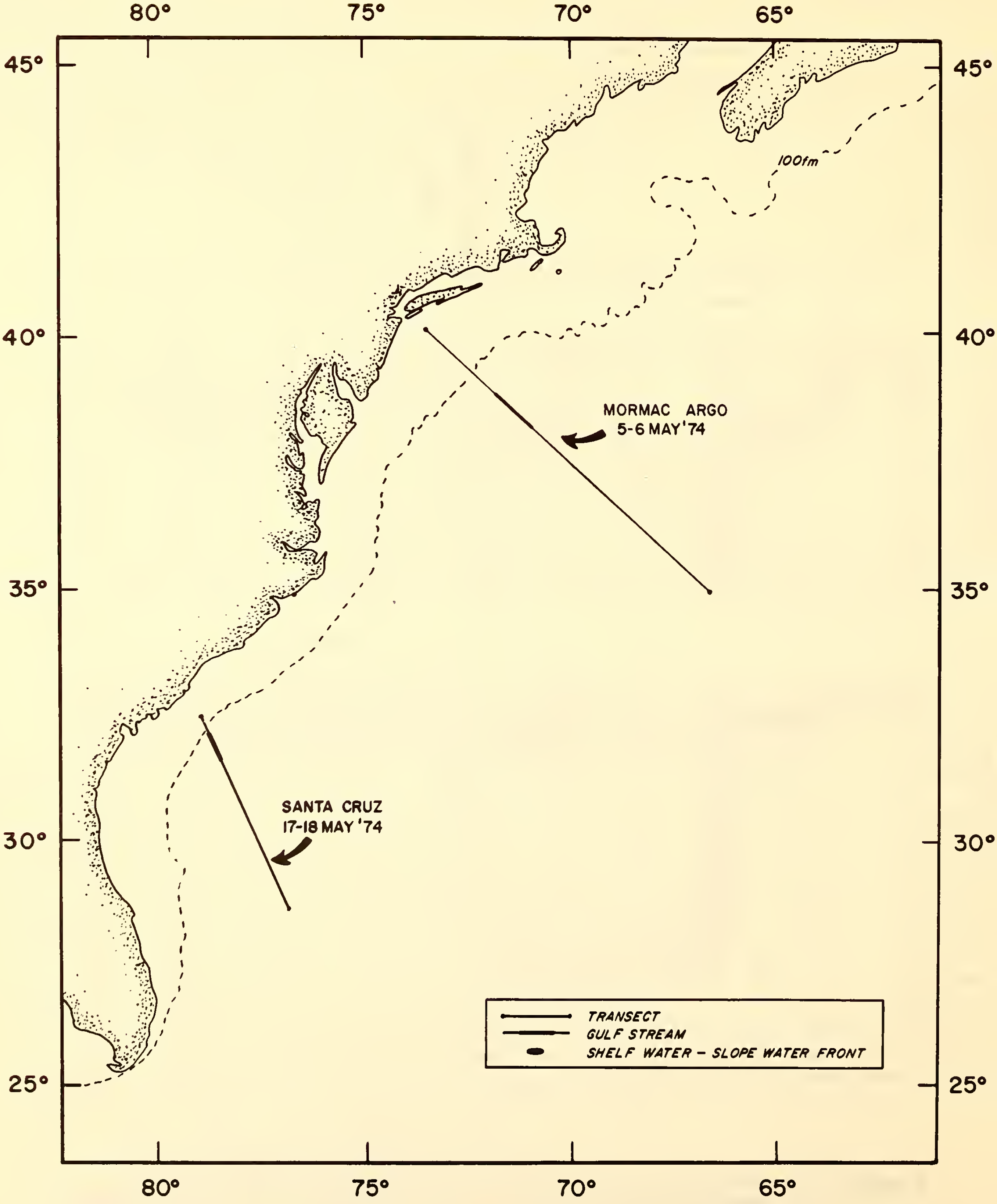


Figure 21.20. Location of Gulf Stream as observed by SOOP Vessels - May 1974.

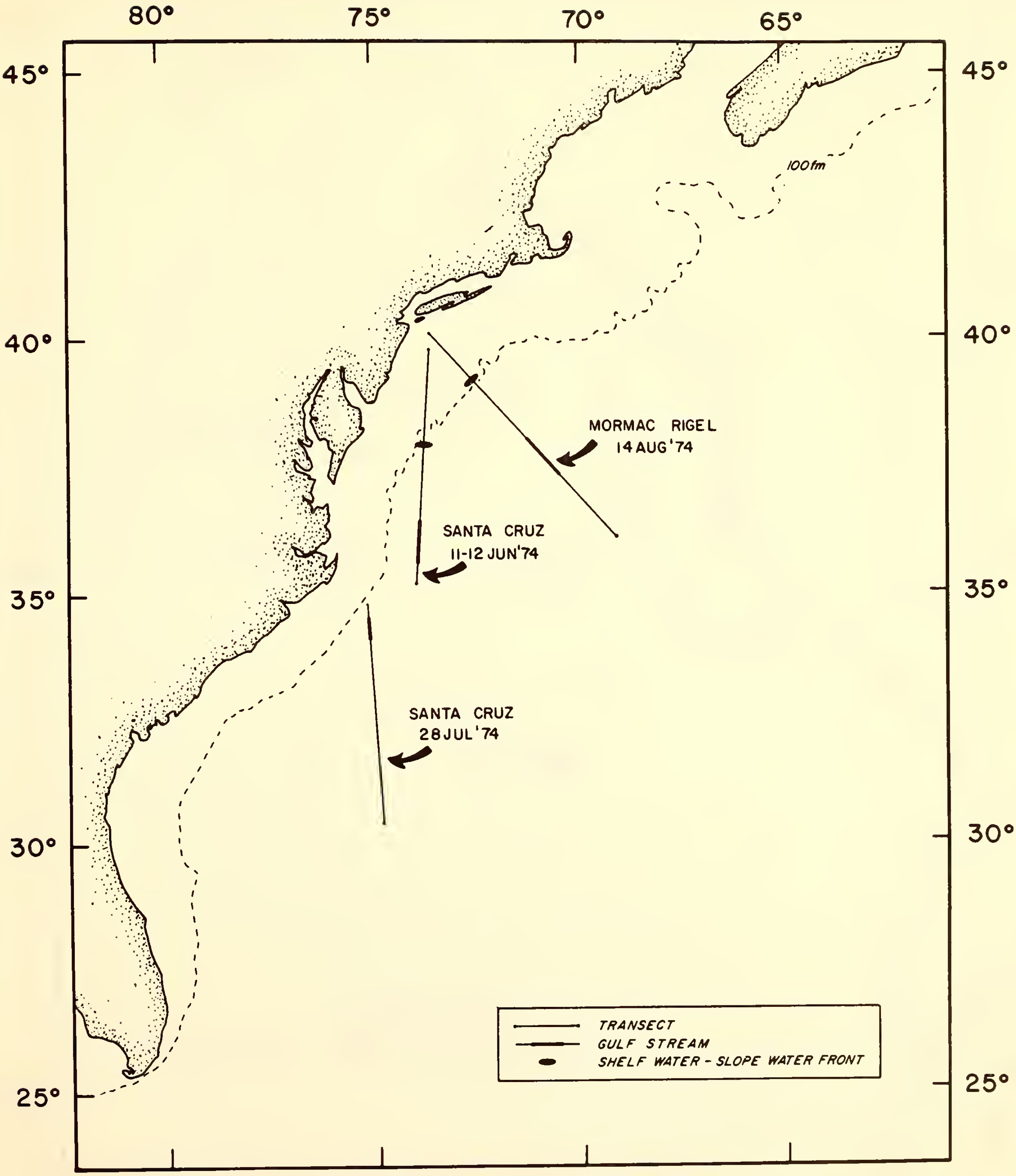


Figure 21.21. Location of Gulf Stream and Shelf Water - Slope Water as observed by SOOP vessels. June-August 1974.

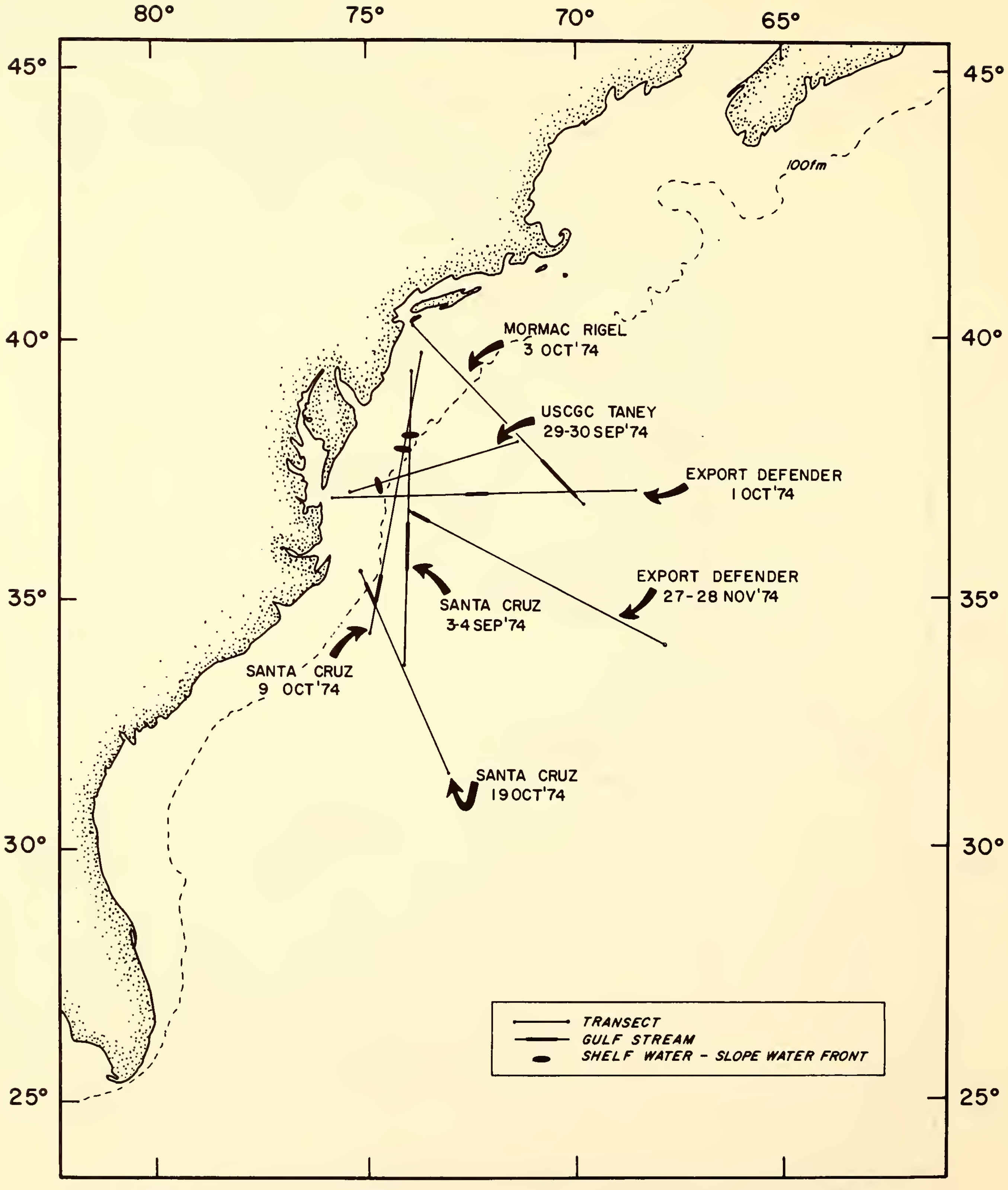


Figure 21.22. Location of Gulf Stream and Shelf Water - Slope front as observed by SOOP vessels. September-November 1974.

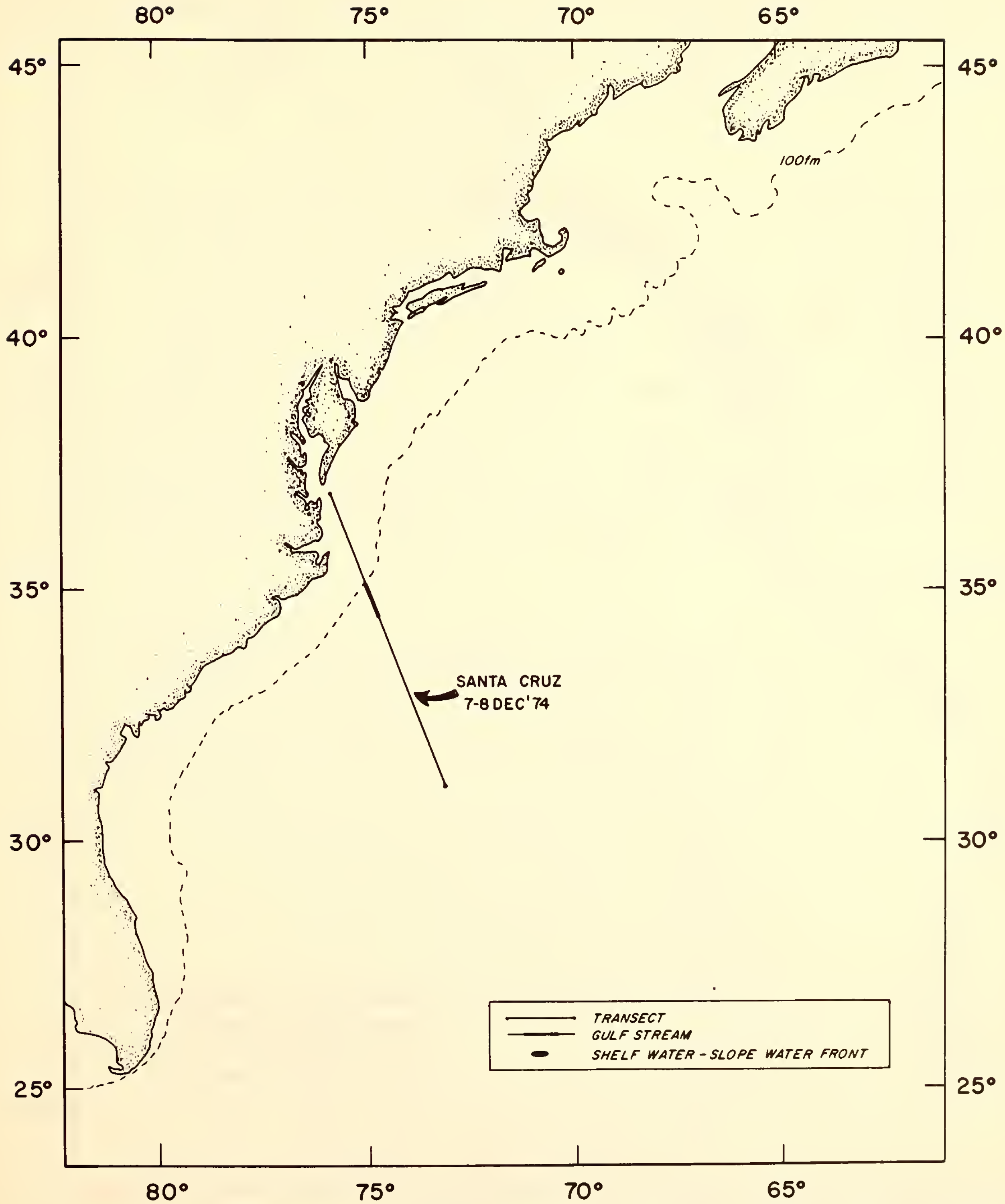


Figure 21.23. Location of Gulf Stream as observed by SOOP vessels -December 1974.

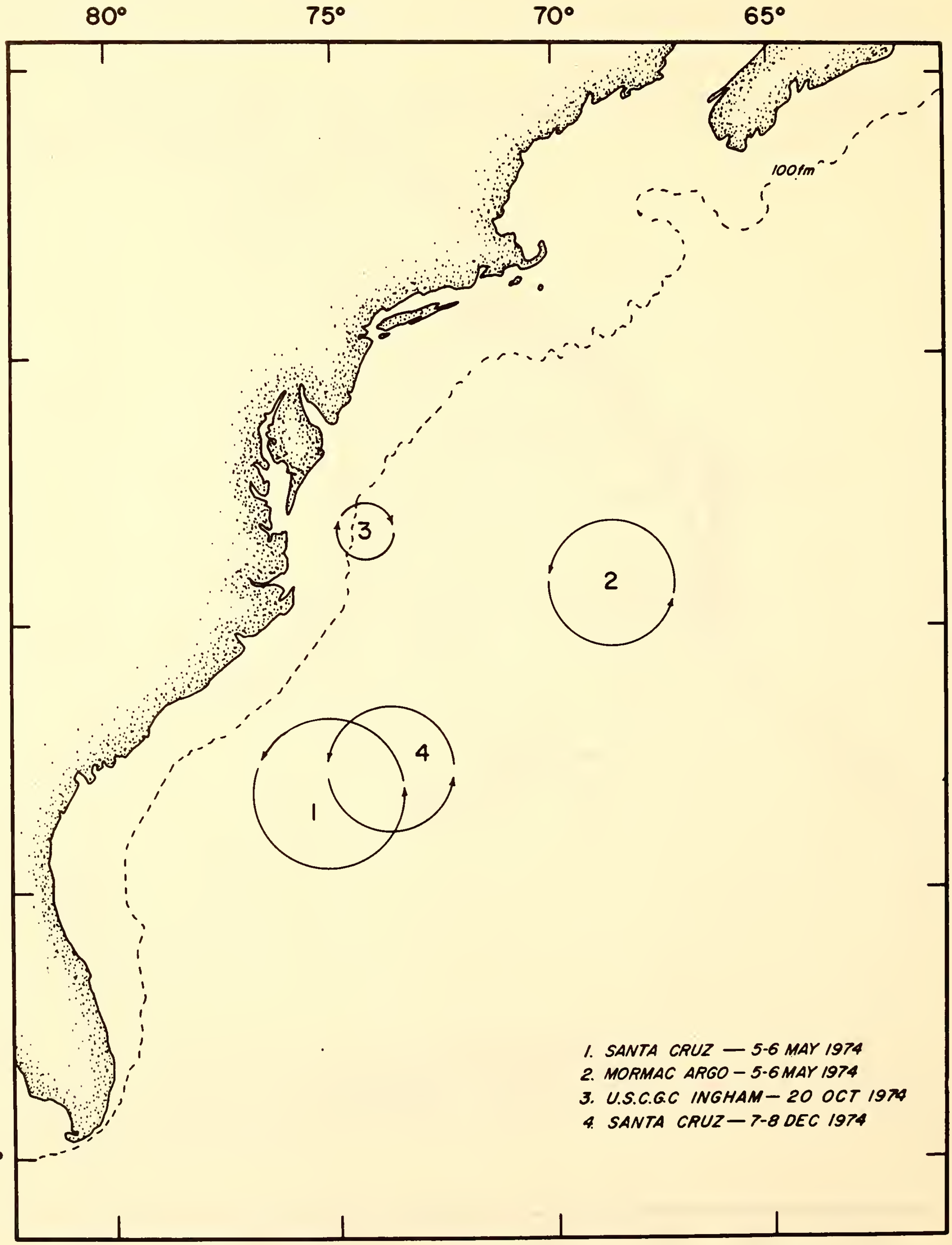


Figure 21.24. Composite plot of eddies located by SOOP vessels - 1974.

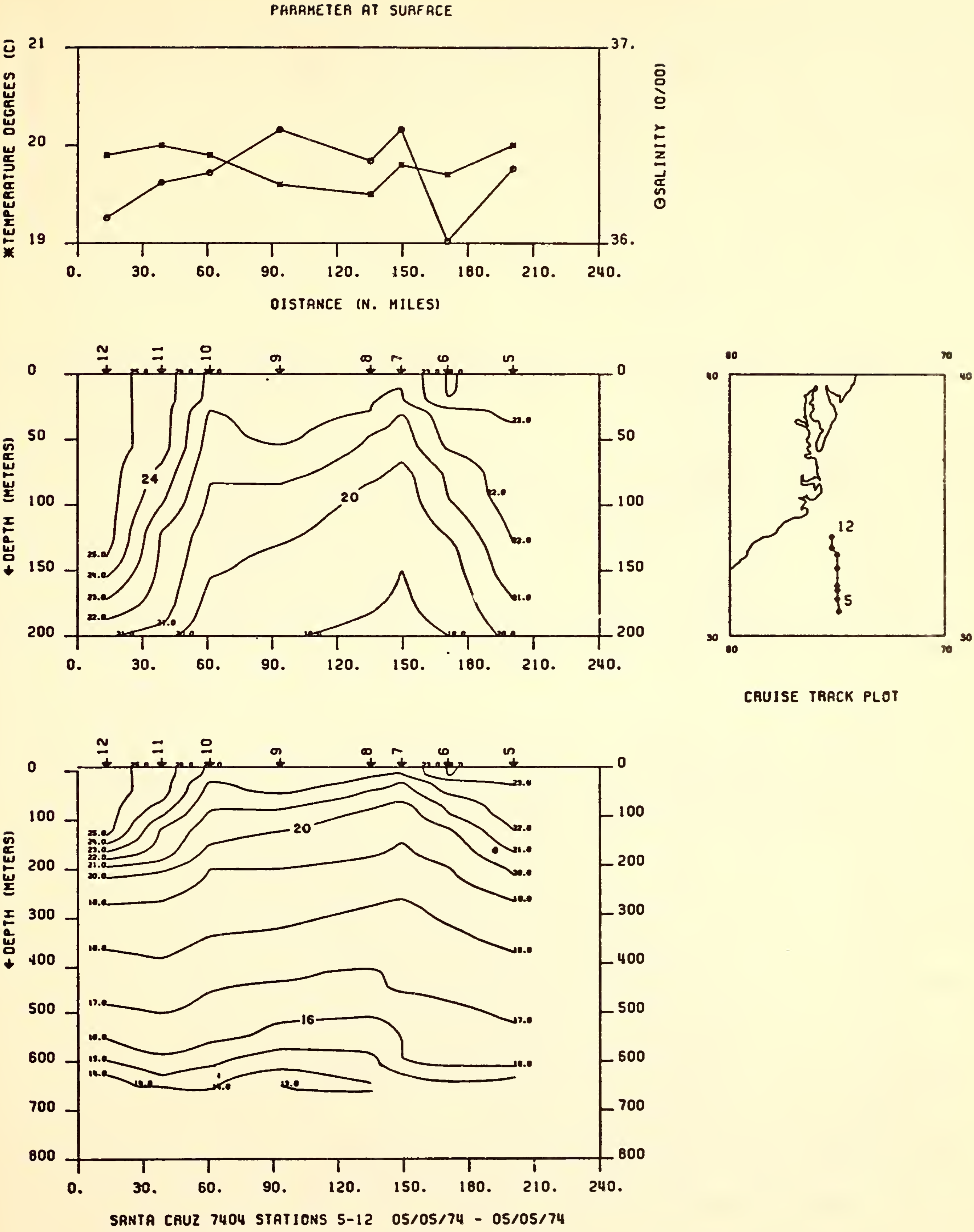


Figure 21.25. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

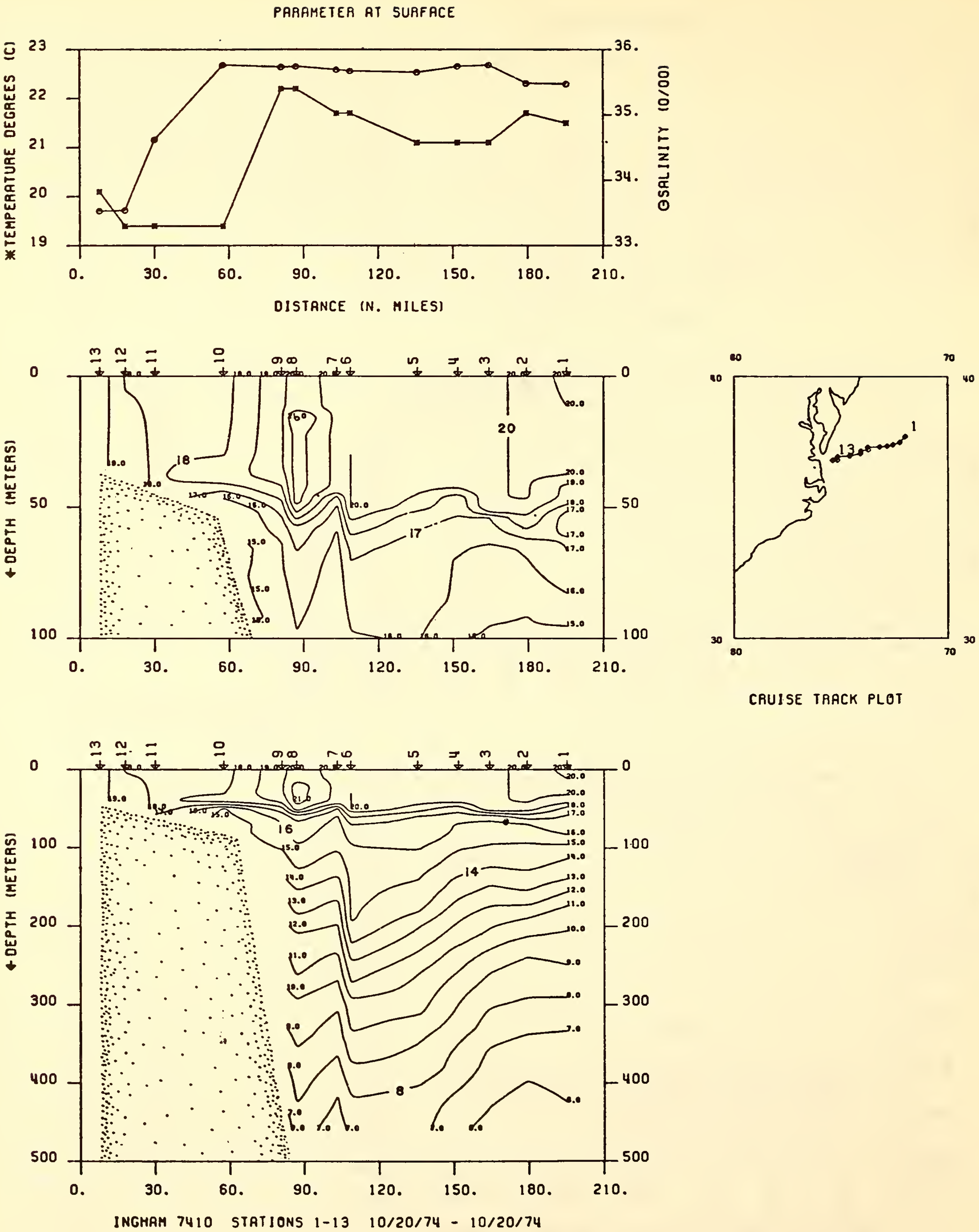


Figure 21.26. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

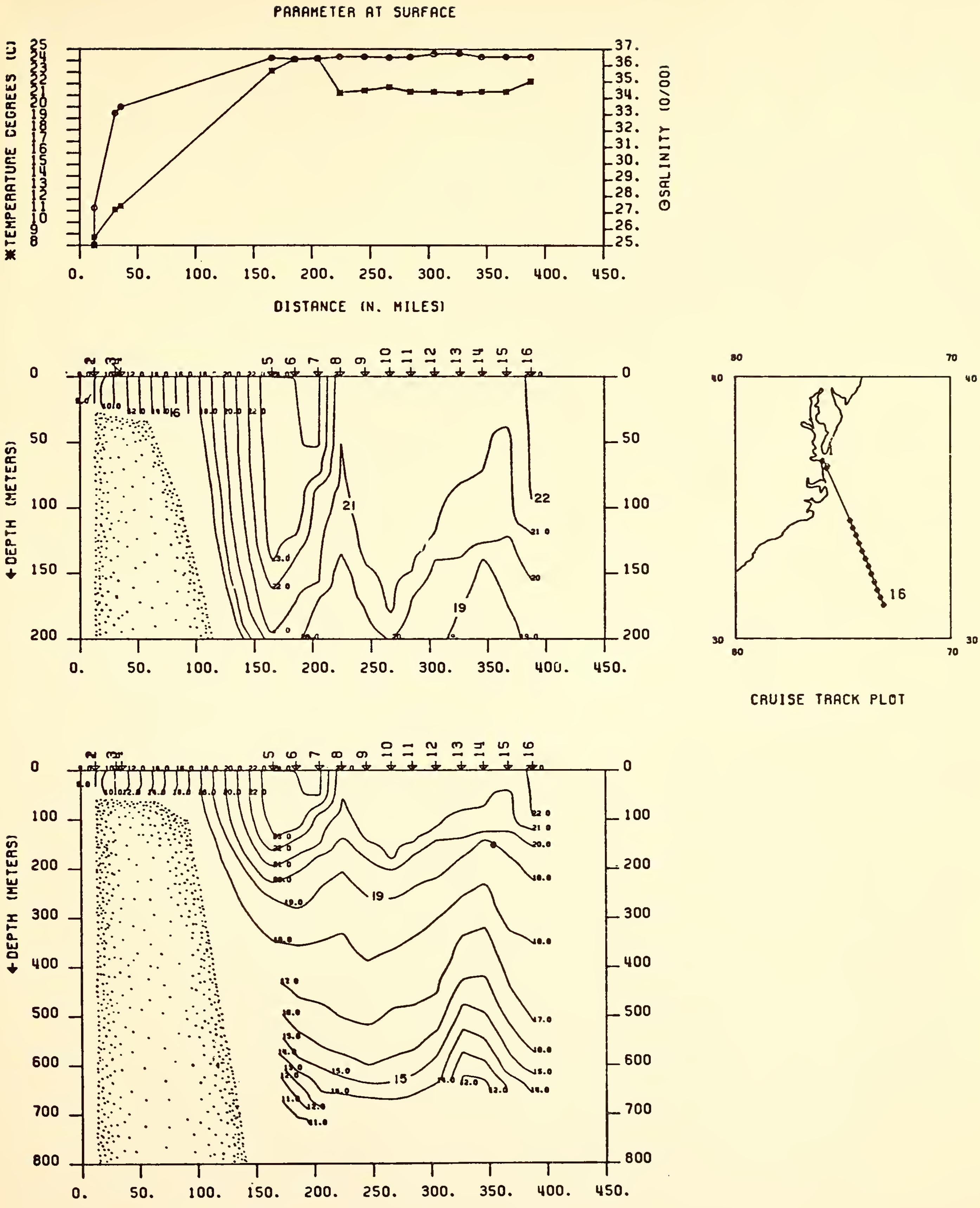


Figure 21.27. Horizontal distribution of sea surface temperature (°C.) and sea surface salinity (°/₀₀) and vertical distribution of temperature (°C.) in the upper 200 and 800 M.

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